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LAKE ERIE WATER LEVEL STUDY. APPENDIX A. REGULATION. VOLUME I.(U)
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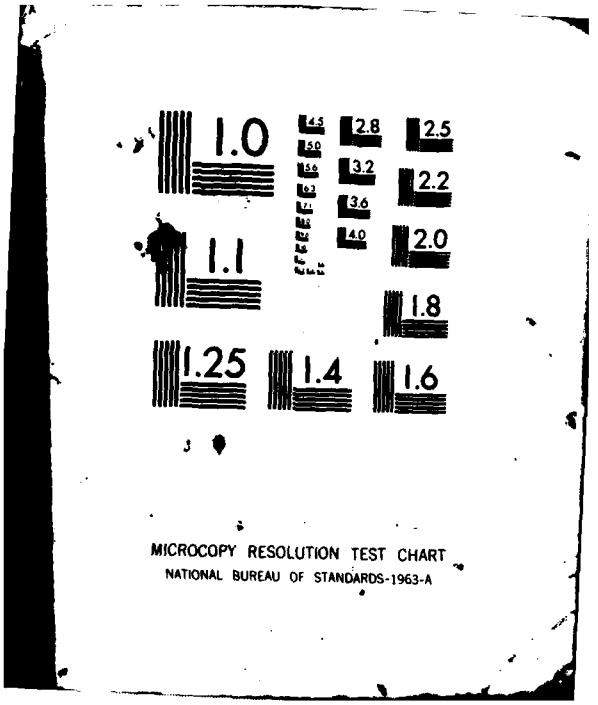
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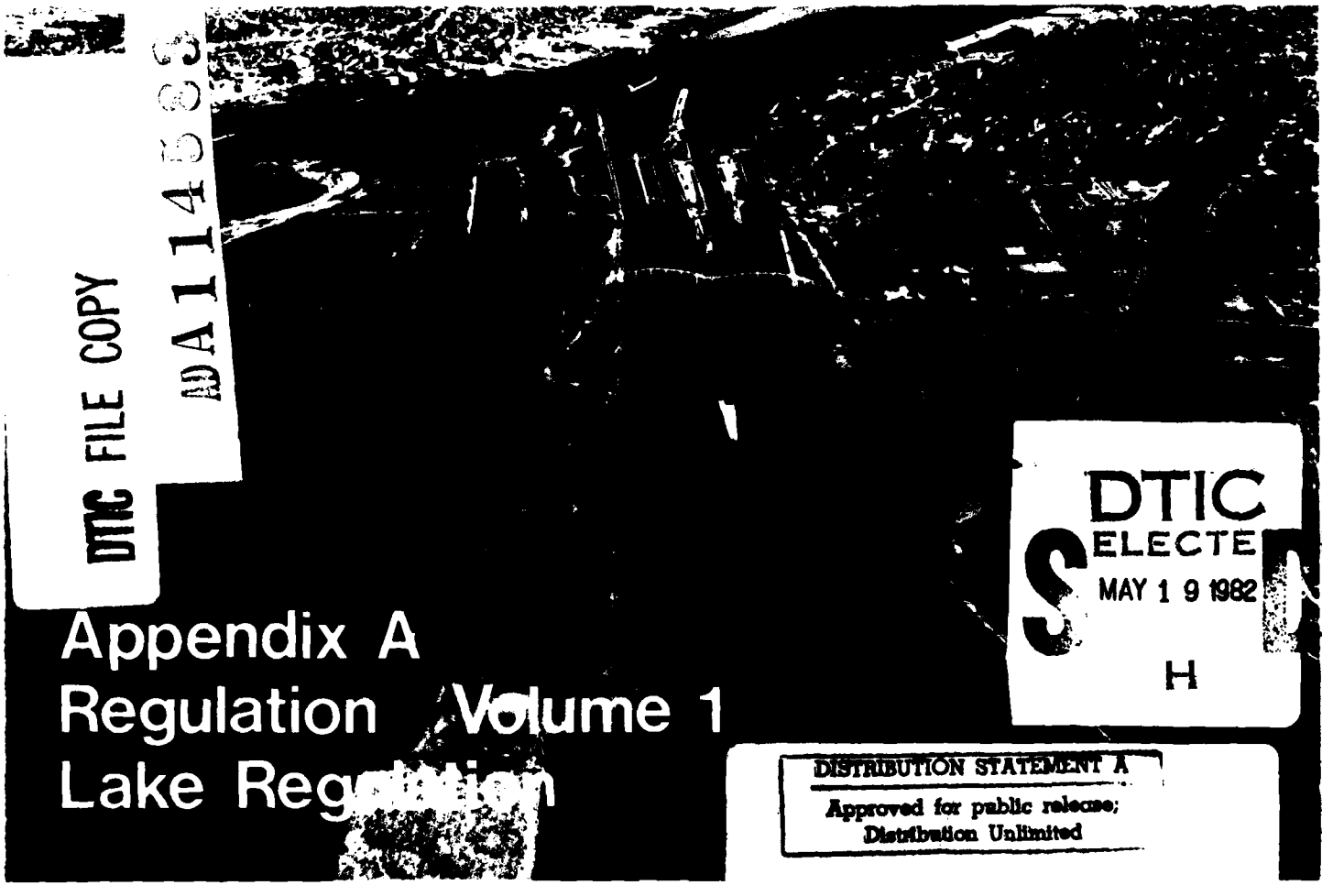

Appendix A
Regulation Volume 1
Lake Regulation

International Lake Erie Regulation Study Board
International Joint Commission

July 1981

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

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This appendix presents the results of the regulation studies undertaken by the International Lake Erie Regulation Study Board, which was established by the International Joint Commission on 3 May 1977.

The purpose of these studies was to develop regulation plans for Lake Erie, employing only partial control of Lake Erie outflow, and determine the effect of such plans, hydrologically, on the entire Great Lakes system. → next page

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20. The results of the hydrologic analysis as presented in this appendix, indicate that limited regulation of Lake Erie provides for a general lowering of the water levels of the system, with impacts being felt on both the maximum and minimum levels.

The results of the entire study are provided in the International Lake Erie Regulation Study main report.

LAKE ERIE REGULATION STUDY

APPENDIX A

LAKE REGULATION

VOLUME 1

REPORT TO THE

INTERNATIONAL JOINT COMMISSION

BY THE

INTERNATIONAL LAKE ERIE REGULATION STUDY BOARD

(UNDER THE REFERENCE OF 21 FEBRUARY 1977)

July 1981

SYNOPSIS

This appendix presents the results of the regulation studies undertaken by the International Lake Erie Regulation Study Board, which was established by the International Joint Commission on 3 May 1977.

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Volume 2 of this appendix contains the coordinated basic data developed and employed in this study. It describes the methods and techniques employed in obtaining the water supply data and development of the basis-of-comparison. Volume 2 also contains tabulations of the final basis-of-comparison data and tabulations of the basic data employed in their derivation.

The report also provides a description of the methods and techniques employed in the development of the level and flow data for the three regulation plans developed in this study, for each of three categories, and a copy of the computer program used is presented.

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Section 1

INTRODUCTION

1.1 General

By letters dated February 21, 1977, the Governments of the United States and Canada requested the International Joint Commission to undertake a study to determine the possibilities for limited regulation of Lake Erie and the consequent effects throughout the Great Lakes basin. This request was made pursuant to Article IX of the Boundary Waters Treaty of 1909, and in light of the first recommendation contained in the Commission's 1976 Report entitled "Further Regulation of the Great Lakes."

The Governments recommended that particular emphasis be placed on examining and reporting on the effects of limited regulation of Lake Erie with respect to: (a) domestic water supply and sanitation; (b) navigation; (c) water supply for power generation and industrial purposes; (d) agriculture; (e) shore property, both public and private; (f) flood control; (g) fish and wildlife, and other environmental aspects; (h) public recreation; and, (i) such other effects and implications which the Commission may deem appropriate and relevant.

1.1.1. Purpose and Scope

This Appendix is part of the final report of the International Lake Erie Regulation Study Board to the International Joint Commission. It documents the regulation studies which have been made under the February 21, 1977 Reference, and presents plans for the regulation of Lake Erie outflows under various restrictive downstream conditions. A description of the events leading to the development of selected plans, along with a complete evaluation of the hydrologic effects which would have resulted had the plans been in operation over the study period 1900-1976, is presented.

All the data which were used during the course of this study, including computer programs, are filed in central locations in Canada and the United States. These data may be obtained at either of the following locations.

Water Planning and Management Branch
Ontario Region
Environment Canada
P.O. Box 5050
Burlington, Ontario, L7R 4A6

or

Buffalo District
U.S. Army Corps of Engineers
1776 Niagara Street
Buffalo, NY 14207

Detailed information regarding the studies performed by the Regulation Subcommittee may be obtained from any of the agencies associated with the participants listed in paragraph 1.1.5.

1.1.2 Description of the Great Lakes System

The St. Lawrence River drainage basin (shown on Figure A-1), of which the Great Lakes basin constitutes the major part, extends a distance of over 2,000 miles from the westerly end of Lake Superior to the Gulf of St. Lawrence on the Atlantic Ocean. The five Great Lakes -- Superior, Michigan, Huron, Erie, and Ontario -- with their connecting rivers and Lake St. Clair, have a water surface area of about 95,000 square miles. The total area of the Great Lakes basin, both land and water, above the easterly end of Lake Ontario is approximately 295,000 square miles.

In the system, water from Lake Superior is discharged into Lakes Michigan-Huron; that from Lakes Michigan-Huron is discharged into Lake Erie; and that from Lake Erie is discharged into Lake Ontario. Regulation of the outflow of any of the lakes of the system, other than Lake Ontario, affects the timing of flow into the lake immediately downstream, which in turn modifies the water supplies to the lakes situated further downstream. A profile of the system is shown on Figure A-2.

Lake Superior has been fully regulated since 1921. On the average, the outflow from Lake Superior is about 30 percent of the total supply to Lakes Michigan-Huron. The Lakes Michigan-Huron total water surface areas are one and one-half times that of Superior.

Because of the broad and deep connection of the Straits of Mackinac, Lakes Michigan and Huron have virtually the same level and are hydraulically considered as one lake. Outflows from Lakes Michigan-Huron are dependent on the levels of both Lakes Michigan-Huron and Lake Erie, but to the greater extent on those of Lakes Michigan-Huron. Because these outflows are in part dependent on Lake Erie levels, control of the outflow of Lake Erie without control of the outflow of Lakes Michigan-Huron would affect the levels of Lakes Michigan-Huron. The regulation of the levels of Lake Erie would also significantly affect the timing of a major portion of the supply of water to Lake Ontario and somewhat the level of Lake Superior and, hence, the water supply to Lakes Michigan-Huron.

Lake Ontario outflow has been controlled since July 1958 and the lake has been regulated since 1960, in accordance with a plan of regulation designed to satisfy the International Joint Commission Orders of Approval. The regulation of Lake Ontario has no effect on the Lake Erie outflows because of the 326-foot difference in level between these two lakes.

1.1.3 Regulation Defined

The word "regulate" is defined by Webster as "to govern or direct according to a rule;" also, "to fix the time, amount, degree, or rate of, by adjusting, rectifying, etc." As understood in this study, the word implies a capability to influence the natural regimen of the lake levels, usually

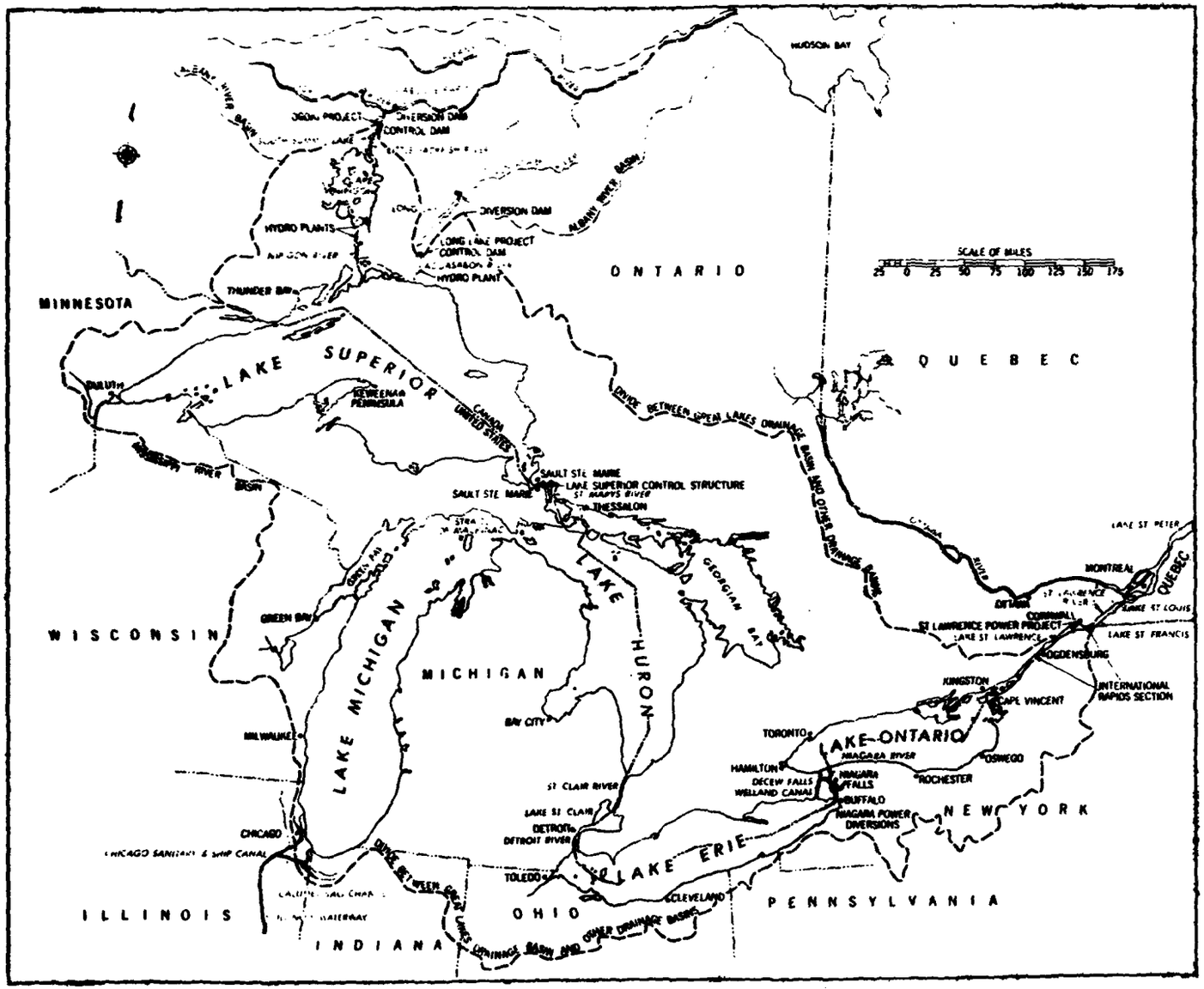


FIGURE A-1

GREAT LAKES-ST. LAWRENCE RIVER DRAINAGE BASIN

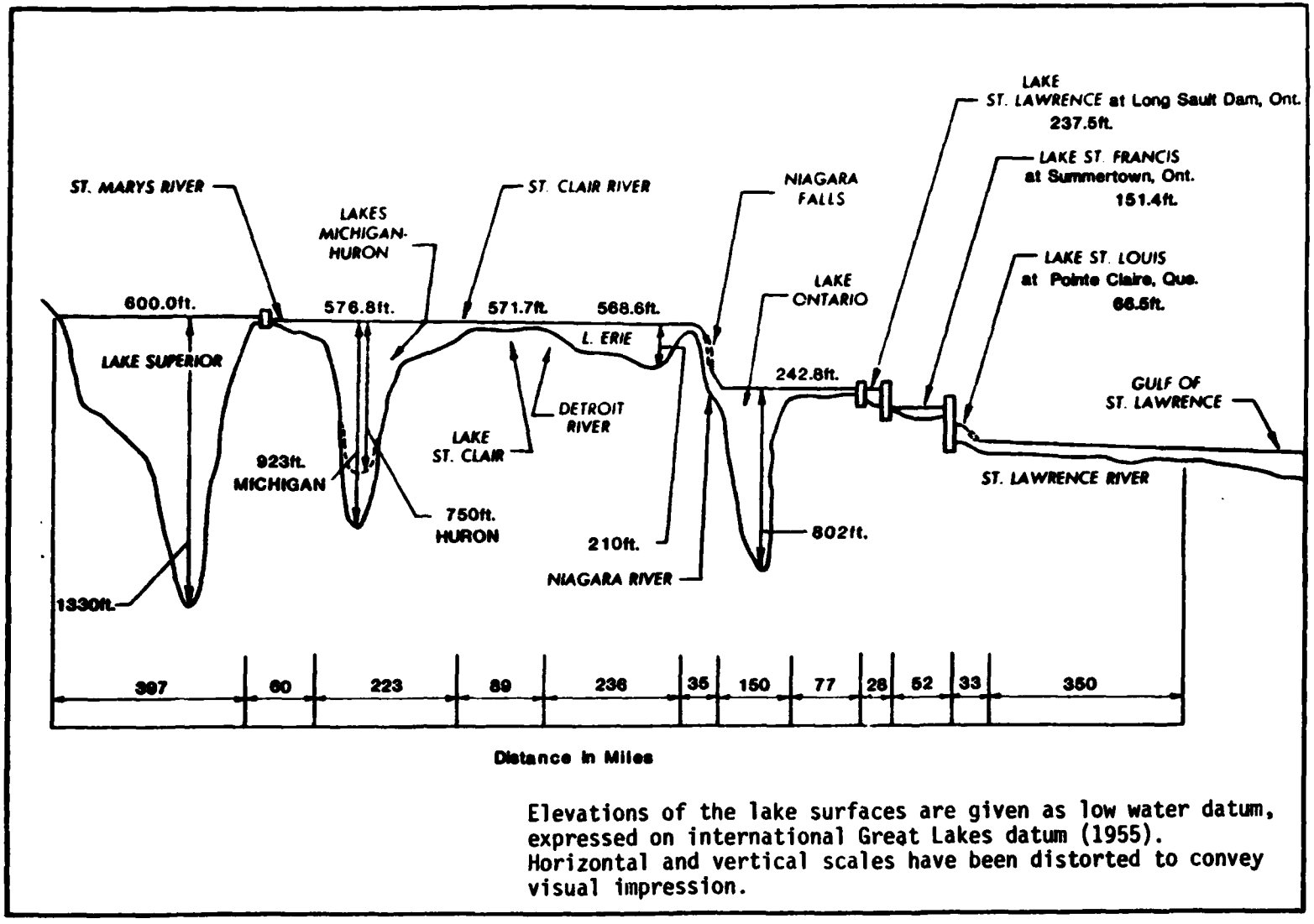


Figure 2-2

FIGURE A-2
PROFILE OF THE GREAT LAKES SYSTEM

through adjustable works constructed by man, by control of the lake's outflow and/or inflow. Exercise of such control in accordance with a predetermined rule (a regulation plan) will accomplish certain results, such as a modification of the extremes of lake levels that would have been experienced without such control.

1.1.4 Regulation Possibilities and Limitations

There are three categories of water level fluctuations on the Great Lakes; these are long term, seasonal, and short-period. Regulation of a lake's outflow mainly affects the long-term fluctuations of the water level, but also impacts on the seasonal variations. It has little impact on the short-period rise or fall other than changing the point of departure from which the rise or fall begins. Each lake will reflect the amount of water received from rain or snow, inflow from the upstream lake and diversion into the lake; and the amount of water lost through evaporation, the outflow river and diversion from the lake. (Ground water has minimal impact on the overall water balance). This process of contribution and removal has resulted in the following range in monthly mean net total supplies over the period 1900-1976.

MONTHLY MEAN NET TOTAL WATER SUPPLY, IN CFS

Lake	Average	Maximum	Minimum	Range
Superior	76,000	359,000	-95,000*	454,000
Michigan-Huron	183,000	594,000	-86,000*	680,000
Erie	198,000	343,000	95,000	248,000
Ontario	232,000	382,000	136,000	246,000

*Negative values indicate that evaporation from the lake surface is greater than the amount of water supplied to the lake.

Due to these large natural variations in water supplies, it is not feasible to regulate any of the lakes so that the monthly mean level throughout the year would be constant. To do so would require that the lake outlet be enlarged to have a monthly mean discharge equivalent to the largest monthly supply (in the case of Lakes Michigan-Huron, this would require an outlet capacity three times that of the existing St. Clair-Detroit River system); further, control works would have to have a capability to reduce the outflow to a monthly rate equivalent to the smallest monthly natural supply of water. In those instances when evaporation exceeds the supply to the lake this would require stopping the outflow entirely and even adding water from other sources. To change the level of individual lakes by one foot in a one month period, the difference between the total supply and total water loss during that month must be of the following equivalent amounts:

Lake Superior	338,000 cfs
Lakes Michigan-Huron	481,000 cfs
Lake Erie	105,000 cfs
Lake Ontario	80,000 cfs

In developing lake level regulation plans, consideration must be given not only to the physical limitations of the system in relation to the wide range of hydrologic conditions in the system, but also to the diverse and sometimes conflicting interests on the Great Lakes which are affected by variations in lake levels. These interests can be placed in the following general categories - coastal zone, navigation, and power. The basic objective of lake regulation is to achieve lake-level conditions on each of the lakes which will provide maximum benefits to each of these interests, with a minimum of adverse effects to any of them. The desires of each of these interests and the factors to be taken into consideration with regard to each are discussed in the following paragraphs.

Coastal Zone Interests: Shore property damage can occur at both high and low lake levels. During low water level periods, major economic damage results from the reduced depths available to recreational boating, small-boat harbors and marinas, and minor damage to untreated timber shoreline structures and substructures may occur due to exposure to the air. In addition, local adverse effects on fish and wildlife may result from extremes in water levels in either direction, although low water levels are generally felt to be more detrimental.

Many factors in combination with the lake level have a direct effect on shore property damage due to flood or erosion. These factors include wind, temporary fluctuation in level due to other causes, the time of year, and the geological formation of the area. There is an almost unlimited number of combinations of lake surface activities, shore characteristics and natural events which produce coastal zone damage. It is difficult to establish a critical mean lake level above which flooding and erosion damage occurs to shore property on each of the lakes. However, surveys and inspections indicate that damage is inconsequential when the lake level is at or below the long-term average elevation. Since it is impractical (because of the wide variation in water supplies) to regulate any of the Great Lakes at this elevation, any regulation plan which would provide benefits to coastal zone interests should reduce extreme levels, and the frequency of occurrence of these levels.

Navigation Interests: The commercial navigation system within the Great Lakes is maintained to accommodate the present fleet and overseas traffic entering and leaving the Great Lakes through the St. Lawrence Seaway. The advertised navigation depths in the system are related to the low water datum plane of reference on each lake. Experience on the lakes over the past 50 years has demonstrated that ship owners take full advantage of all available depths. There are vessels on the Great Lakes of such characteristics that they can load to full draft only during periods of extreme high levels. Hence, navigation interests advocate maintaining relatively high minimum levels throughout the system during the navigation season to allow greater draft for vessels, as well as maintaining high minimum flows in the connecting channels during the same period to maintain the depths in those channels.

There is, however, a somewhat lesser concern with maximum levels which govern elevations at the docks, and with the frequency and duration of high flows which affect river currents and velocities.

Power Interests: Power interests desire generally high lake stages combined with a range of stage adequate to improve the distribution of lake outflows for greater firm power capacity. They also desire flexibility of operations which would permit short-period variations in the daily, weekly or monthly mean flow and which would, in effect, increase the dependable flow available for power during peakload periods. In the design of channel enlargements above a powerhouse, it would be advantageous to the power interests to have the river and lake levels as high as possible, since maintaining high levels would help reduce the cost of excavating in those channels. Also of importance to the power interests is that the flows during the winter months should be such as to ensure the formation and retention of a stable ice cover on the outflow rivers. This would minimize ice jams in the rivers, minimize clogging of turbine intakes, and make it possible to maintain the discharge capacity necessary to meet high load requirements during the winter season. Since seasonal load requirements are generally greater during the winter months, the minimum flows during the winter should be greater than those for the summer.

In view of the proportions of the physical constraints of the system, the variations in water supply and the diverse interests involved, disruption of the seasonal pattern or changes in the long-term historic relationship between lakes would result in large losses to specific interests. Hence, if regulation is to provide maximum benefit without loss to any users of the system, it can, in only a limited way, reduce the variance of levels about the mean, reduce the variance of flows, change the mean level, or provide a combination of all three of the foregoing effects. The method employed in this study for defining the possibilities and limitations to changing the regime of levels was to develop and test regulation plans with supplies that have occurred in the past. The resulting plans were employed to establish the degree to which regulation can be accomplished and at what cost or benefit to the various interests.

1.1.5 Organization

In 1977, the International Lake Erie Regulation Study Board formed a Working Committee to assemble data and to conduct the necessary engineering studies required to reply to the Reference. To carry out its responsibilities the Working Committee established Subcommittees for each of the major phases of the study.

The Regulation Subcommittee, appointed by the Working Committee on June 7, 1977, is composed of two members each from Canada and the United States:

Canada	United States
D. F. Witherspoon, Environment Canada	B. G. DeCooke, Detroit District, Corps of Engineers
P. Yee " "	W. Erdle, Buffalo District, Corps of Engineers

The assigned mission of the Regulation Subcommittee was to: (a) develop the required basic data needed for regulation studies; (b) develop a basis-of-comparison for the regulation studies; (c) develop regulation plans for Lake Erie employing only partial control of the outflow; (d) evaluate the effect of the plans, hydrologically, on the entire Great Lakes system; (e) determine the impact on the Lake Erie regulation plans of diversion management being developed by the International Great Lakes Diversion and Consumptive Uses Study Board; and, (f) provide input to the other subcommittees so these plans can be evaluated environmentally and economically.

1.2 Study Procedures

To address the issues in the Government's Reference to the IJC, related to the combined regulation of Lakes Erie and Ontario, the procedure followed in this study consists of: (1) the development of a series of regulation plans to address the various regulation possibilities; (2) the evaluation of these plans, hydrologically, economically and environmentally, to determine the benefits and dis-benefits associated with the regulation plans; and (3) the design of the necessary regulatory works including a determination of the cost associated therewith. Section 3 of this document covers in detail the studies conducted and results obtained in part under items 1 and 2 of the outlined procedure.

Section 2

BASIC DATA

2.1 General

It was evident early in the study that the coordinated water supply data which were available, as a result of prior studies, required updating and extending to cover the study period being utilized in formulation of the basis-of-comparison and for development of regulation plans. A detailed description of the development of the required data, tabulation of the final coordinated data and the basic data employed in their derivation, is given in Volume 2 to this Appendix entitled "Coordinated Basic Data." The following paragraphs provide a summary of that information.

2.2 Selected Study Period

Although observations of the water levels of the Great Lakes have been taken almost continuously since 1860, only a few discharge measurements of the outflows from the lakes were made prior to the turn of the century. In order to use a uniform, consistent and reliable set of observations for each of the lakes and their outlet rivers, and also to have a reasonably long record for developing and evaluating regulation plans, the period from January 1900 to December 1976 was selected. This 77-year period is known as the "study period" throughout this report. This period contains basin-wide drought periods, such as those of the mid-1930's and mid-1960's, as well as several high supply periods, such as those in 1928-1929, 1951-1952 and the 1970's. Hence, it was considered that the period 1900-1976 was adequate for providing an assessment of the effects of the regulation plans.

2.3 Recorded Data

The recorded data used to calculate the water supplies and the basis-of-comparison for the regulation plans were taken from records on file in the United States at the National Oceanic and Atmospheric Administration, Department of Commerce, and at the U. S. Army Engineer District, Detroit, Department of Army; and, in Canada, at the Inland Waters Directorate, Environment Canada. The data developed by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, and agreed to by user federal agencies of both countries, were employed where possible. Where coordinated data did not exist, provisional data were developed by the Regulation Subcommittee for use in the study.

2.4 Assumptions

To determine the required water supply data and to develop the basis-of-comparison, the following assumptions were made:

1. No adjustments would be made for changes in the hydraulic and hydrologic characteristics (such as tributary stream regulation, increased urbanization, consumptive use, etc.) of the Great Lakes basin, but would be as they occurred over the study period, and as reflected in the recorded data.

2. Due to the large surface area of each of the Great Lakes in comparison to changes in the area as a result of changes in stage, a single storage conversion constant, relating the volume of water represented by a given change in stage to cfs-months, would be employed over the entire range of levels for each lake. The constants are as follows:

Lake Superior	=	.00296 foot per thousand cubic feet per second for one month (TCFS-mo.) or 337,800 cubic feet per second for each foot (CFS-mo./ft.)
Lake Michigan-Huron	=	.00208 ft./TCFS-mo. or 480,800 CFS-mo./ft.
Lake Erie	=	.00951 ft./TCFS-mo. or 105,200 CFS-mo./ft.
Lake Ontario	=	.0125 ft./TCFS-mo. or 80,000 CFS-mo./ft.

3. All months have the same number of days (30.4 days).

2.5 Derived Data

Due to the larger lake areas, of Lake Superior and Lakes Michigan-Huron, their levels respond to changes in water supply much more slowly than do the levels of Lakes Erie and Ontario (Lake Ontario responds six times as fast as Lakes Michigan-Huron). For this reason, the basic data used in this study were developed and coordinated for monthly periods on Lakes Superior and Michigan-Huron and for quarter-monthly periods on Lakes Erie and Ontario. However, since Lake St. Clair reflects conditions on Lakes Michigan-Huron and Erie, it was necessary to employ monthly periods on that lake. Data derived for testing lake regulation plans and for formulating the basis-of-comparison are described in the following subsections.

2.5.1 Net Basin Supplies

Net basin supply is a term used to describe the water which a lake receives from precipitation, on both its surface and its own land drainage basin, less the net effect of evaporation and condensation on the lake surface. Although presently available techniques do not permit the accurate determination of these factors separately, the net basin supplies can be computed quite accurately by employing reliable lake level, inflow, outflow and diversion records. The relationship used is as follows:

$$NBS = S + O - I \pm D$$

where:

NBS = Net basin supply.
S = Change in storage, based on change in level from beginning to end-of-period.
O = Average outflow from lake through outflow river.
I = Average inflow to lake from inflow river.
D = Diversion into the basin (-) and out of the basin (+).

All terms in the above relationship are expressed in consistent units, usually cubic feet per second, for the given period.

2.5.2 Winter and Weed Retardation

The outflow through the St. Marys River is regulated by the International Lake Superior Board of Control under authority of the International Joint Commission. The physical control is achieved by a dam and other structures at the head of the St. Marys Rapids at Sault Ste. Marie, Michigan and Ontario. Under present regulation conditions, the winter retardation effect on the discharges is virtually zero. Since the basis-of-comparison condition for Lake Superior was considered to be the present regulated condition, it was not necessary to consider winter retardation in the St. Marys River.

Lakes Michigan-Huron generally do not freeze over completely during the winter, primarily due to the influence of wind and the heat stored in the lake. The ice which forms in exposed central parts of the lake is continually broken up and moved about by the action of the wind. Some of this ice finds its way into the St. Clair River. As a result of these heavy runs of ice, jams occur which materially reduce the normal flow and in turn affect both the upstream and downstream levels. The supply of ice delivered to the river and the consequent degree of jamming is highly variable (January through March average flow retardation is 23,000 cfs) and is an important factor of the natural winter regime. Hence, any plan which does not contemplate control works in this channel must give consideration to the month-by-month magnitude of this retardation. Winter retardation in the St. Clair River was computed for use in this study by subtracting the recorded St. Clair River flow from the corresponding discharge computed from the open water discharge relationship for the Harbor Beach and St. Clair Shores (Grosse Pointe) gauges.

Lake St. Clair normally freezes over in early winter and shields the Detroit River from heavy ice runs. The Detroit River itself frequently freezes over in its lower reaches. However, due to the size of Lake St. Clair, even a small retardation (January through March average is 4,000 cfs) influences its level regime. Winter retardation in the Detroit River was determined to be the difference between the flow computed from the open water discharge relationship for the St. Clair Shores (Grosse Pointe) and Cleveland gauges and the recorded flow.

As in the case of Lake Huron, the principal problem with ice in Lake Erie and the Niagara River results from break-up of lake ice fields and the wind

pushing the ice into the river. Since 1964, an ice boom has been installed each winter near the head of the Niagara River. Its purposes are to facilitate early formation of an ice cover and to reduce the frequency and severity of ice runs into the Niagara River. The presence of the ice boom has reduced the ice retardation of Niagara River flow to a level which can be considered insignificant. However, since the outlet conditions of 1953 were adopted as the basis to be used for comparing regulation plans, average winter retardation was assumed for the Niagara River over the period of record.

In the summer, weeds affect the flow in the Niagara River. In studies conducted by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, it was determined that this effect was about the same every summer. Therefore, average weed retardations, as computed by the Coordinating Committee, were employed.

The water level of Lake Ontario and the outflow through the St. Lawrence River are regulated by the International St. Lawrence River Board of Control under the authority and "Orders of Approval" of the International Joint Commission. The physical control is achieved by structures located on the St. Lawrence River at Massena, New York and Cornwall, Ontario. Since the basis-of-comparison condition for Lake Ontario was considered to be the present regulation condition, it was not necessary to consider winter retardation in the St. Lawrence River.

2.5.3 Basis-of-Comparison

The recorded data reflect the effects of changes in the regimen of the lakes and their connecting channels which have occurred over the study period (1900-1976). The principal changes to the system are man-made and consist of changes in the amount of diversion into and out of the Great Lakes basin, alterations in the configuration of the connecting channels and the construction of control works at the outlets of Lake Superior and Lake Ontario.

In order to permit the hydrologic comparison of various regulation plans on a constant basis over the period of study, a set of uniform conditions within the Great Lakes system was adopted and corresponding adjustments to the recorded levels and outflows were made. The levels and flows occurring under these uniform conditions are also employed to assess the possible benefits/losses resulting under the various plans.

The conditions selected for the basis-of-comparison are as follows:

1. A constant diversion of 5,000 cubic feet per second into Lake Superior by way of Long Lac and Ogoki Diversions. These diversions were the subject of an exchange of notes dated October 14 and 31 and November 7, 1940, between the Governments of the United States and Canada. (Recent data have shown that the historical rate has been about 5,600 cfs).

2. Lake Superior regulated in accordance with Regulation Plan 1977, which is the plan currently being used by the International Lake Superior Board of Control.

3. A constant diversion of 3,200 cubic feet per second out of Lake Michigan at Chicago. This is the maximum allowable diversion at Chicago by decree of the U. S. Supreme Court dated June 12, 1967.

4. The 1962 outlet conditions for Lake Huron. This represents the current Lake Huron outlet condition which has existed since completion of the 27-foot navigation channel dredging in 1962.

5. A constant diversion, by way of the Welland Canal, of 7,000 cfs out of Lake Erie and into Lake Ontario. This is the approximate average diversion through the Welland Canal which existed during the period 1950-1976. (More recent data have shown the current rate of diversion to be closer to 9,200 cfs).

6. 1953 outlet conditions for Lake Erie. In its 1953 report on the Preservation and Enhancement of Niagara Falls, the International Joint Commission considered it essential that the relationship existing at that time between the Niagara River flow and the Chippewa-Grass Island Pool level be maintained following the commencement of operation of the Chippewa-Grass Island Pool Control Structure and power diversions as permitted by the 1950 Niagara Treaty.

7. Lake Ontario regulated during the period 1900-1976 in accordance with Plan 1958-D, incorporating discretionary deviations from the plan which have occurred since 1960. Some minor adjustments were necessary in the recorded discretionary deviations values employed after 1973 to maintain St. Lawrence River profiles and to accommodate changes in upstream water supplies. (See paragraph 3.7 for discussion of adjustments to Plan 1958-D to provide data for comparison under Category 3 of this study).

8. Recorded conditions for the Ottawa River and local inflow to the St. Lawrence River.

The monthly mean levels and outflows for each lake under the basis-of-comparison were obtained by routing through the system the net basin supply, assuming a regime defined by the foregoing conditions. The effect of changing conditions (during the study period) in channel configurations, diversions and regulations, thus have been removed from the data. No adjustments were made in the data for the progressive effects of crustal movement and regulation of tributaries, variations in winter and weed retardations and the varying rates of consumptive uses.

Section 3

DEVELOPMENT OF REGULATION PLANS

3.1 General

Full regulation requires works which can vary the outflow from zero to the maximum hydraulic capacity of the outlet. In the case of Lake Erie this would require full control of the flow through the Niagara River and Welland Canal. Limited regulation requires works which can modify, but cannot control fully, the total outflow from the lake. Such works would only be required at selected points in the system. In this study limited regulation of Lake Erie has been investigated in conjunction with changes to the existing full regulation of Lake Ontario in order to accommodate the limited regulation of Lake Erie outflows.

To address the issues raised in the Government's Reference, the regulation studies were divided into three categories. Categories 1 and 2 considered Lake Erie regulation constrained by the present IJC "Orders of Approval" for Lake Ontario and the existing channels of the St. Lawrence River. However, they differed in that Category 1 considered Lake Ontario to be regulated in accordance with Plan 1958-D with discretionary flow deviations from that plan as exercised by the Board during actual operations; whereas, under Category 2, Plan 1958-D was modified to accommodate Lake Erie limited regulation and to satisfy the IJC Lake Ontario "Orders of Approval" to the same degree that occurred under the historic test and under operation since 1960 as represented by the basis-of-comparison. Category 3 considered Lake Ontario regulation plan modification, channel modification and/or remedial measures in the St. Lawrence River to accommodate regulation of Lake Erie and to satisfy the IJC Lake Ontario "Orders of Approval", as written, over the entire test period (1900-1976).

A three-stage procedure was employed in the development of the limited Lake Erie regulation plans presented. Stage (1) consisted of the development of an index which would be employed as an indicator as to when to increase the outflow from Lake Erie; Stage (2) consisted of the development of series of regulation plans for Lake Erie over a wide range of increases in Lake Erie outflows; and Stage (3) consisted of evaluating the impacts on Lake Ontario of the increased inflows from Lake Erie and of making the necessary revisions to Plan 1958-D outflows to satisfy the objectives of Categories 2 and 3.

Stage (2) was further divided into three general groups; plans which confined activities (structures and dredging) to the Niagara River; plans which used the Black Rock Canal with a channel cut through Squaw Island for additional capacity; and, lastly, plans which used the Black Rock Lock to pass increased flows.

3.2 Regulation Objective and Criteria

The primary objective of this study is to determine the feasibility of lowering the high levels of Lake Erie by increasing its outflow during periods of high water supply. The plans presented use channel improvements and control structures in either the Niagara River or the Black Rock Canal. In the case where the Niagara River is employed to obtain the additional capacity, full utilization of increased capacity of the regulatory works is possible at all times. However, in the case where the Black Rock Canal is used, it is necessary to operate the structure intermittently resulting in the full capacity of the works only being employed about 60% of the time on an annual basis. Intermittent operation of the control structure is necessary to minimize the impacts on canal navigation and lock maintenance, and to provide for recreational boating use of the canal.

Since one of the overall study objectives is to determine the feasibility and impacts of limited regulation of Lake Erie, no specific criteria for the regulation of that lake have been established. The broad objective was to provide the maximum reduction in the frequency of occurrence of above normal Lake Erie levels, while maintaining as near as possible the long-term mean level and the frequency of occurrence of below normal levels. In evaluation of the impact on Lake Ontario, the International Joint Commission criteria and other requirements as given in the "Orders of Approval" of October 1952 and the 1956 Supplementary Order were used in comparing the performance of various regulation plans.

3.3 Index Development

The total water supply to Lake Erie has two components: (1) that portion which is supplied from the upper lakes; and (2) that portion which is contributed from its own basin. Of the two, that which is (in the long-term) contributed from the upper lakes is the most important. On the average, 80 percent of the water supply to Lake Erie comes from Lakes Superior and Michigan-Huron, with only about 20 percent being contributed by its own basin. Therefore, the levels of the upper lakes and/or the water supply to those lakes provide an indicator as to future water supply conditions to Lake Erie.

Shown on Figure A-3 are two hydrographs which could be used for advanced indication of higher or lower water level conditions on Lake Erie. The upper is a plot of the 12-month moving mean of water levels on Lakes Michigan-Huron, while the lower curve is a similar plot of net basin supplies to that lake. The diagram shows that the water supply indicator tends to move from below to above its average and vice-versa, sometime prior to the lake level indicator making similar excursions above or below its average. Hence, employing water supply as an indicator would permit an earlier increase in Lake Erie outflow in a rising lake level situation than the level index, and an earlier decrease in those rates in a falling lake level situation.

LAKE LEVEL VS WATER SUPPLY
(DEVELOPMENT OF TRIGGER)

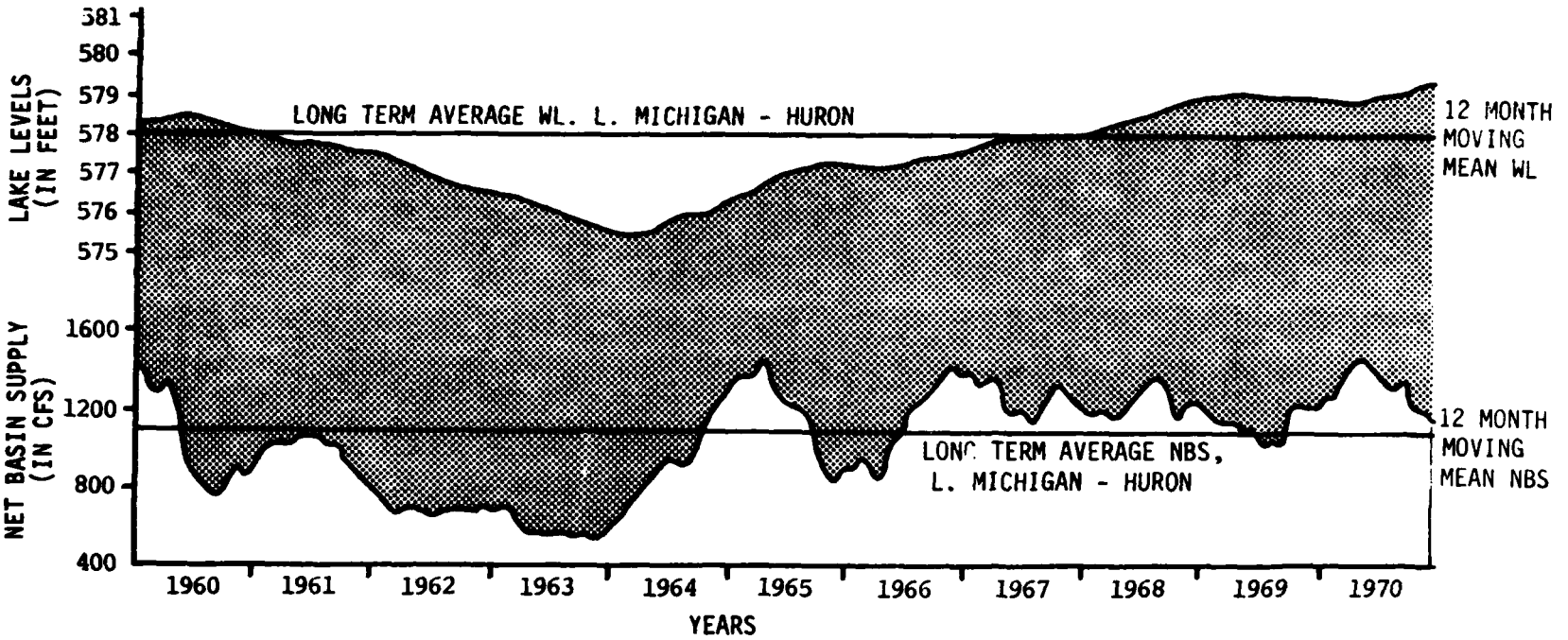


FIGURE A-3

Based upon the above rationale, the water supply to Lakes Superior and Michigan-Huron was selected as an indicator of future water supplies to Lake Erie. In this study, to provide a smooth transition during changing supply conditions, a 12-month moving mean water supply to these lakes was employed as the trigger.

3.4 Lake Erie Regulation Plans

As noted previously, the regulation studies were conducted under three separate categories. Category 1 develops the necessary plans for Lake Erie, and Categories 2 and 3 deal additionally with modifications to Lake Ontario Regulation Plan 1958-D and the necessary changes to the St. Lawrence River to handle an increased flow. As noted in Section 3.1, plans for limited Lake Erie regulation under each category were subdivided into three groups; those which require a regulatory structure in the Niagara River, plans which use a diversion channel cut through Squaw Island, and lastly plans which use the Black Rock Lock to discharge additional quantities of water from Lake Erie. All of these plans are considered limited regulation schemes since none of the plans provide for full control of the outflow. The following paragraphs describe Category 1 plans for each of these groups.

3.4.1 Niagara River Plans (N-Series)

Regulation plans in this series require increased channel capacity by dredging and a control structure which extends partially across the Niagara River. The structure would be operated to increase the outflow from Lake Erie (by taking advantage of the dredging) whenever the water supply indicator for the upper Great Lakes is at or above normal. Whenever the water supply in the upper Great Lakes drops below normal, the total Lake Erie outflow would revert to that which would occur under the preproject conditions. To provide for a range of impacts, costs, and benefits, a series of (N) plans were tested which increased the outflow from Lake Erie from 5,000 cfs up to 30,000 cfs in increments of 5,000 cfs. The resulting outflows from Lake Erie, under Category 1, for each of these plans, were routed through Lake Ontario in accordance with Regulation Plan 1958-D. Under Category 1, there is no attempt to modify Plan 1958-D to accommodate this increased inflow to Lake Ontario nor to satisfy the IJC criteria for the regulation of Lake Ontario. The results of these tests are shown on Table A-1. The plan names denote the capacity and type of structure to be used, e.g., 25N represents a regulation plan in the Niagara River requiring a 25,000 cfs capacity increase.

3.4.2 Black Rock Canal - Squaw Island Plans (S-Series)

Regulation plans in the series of "S" plans utilize the Black Rock Canal-Squaw Island structure to pass additional water out of Lake Erie. Water enters the canal in the Buffalo Harbor area on Lake Erie and is returned to the Niagara River downstream from the river's natural hydraulic control. A diversion channel would be constructed across Squaw Island to increase and

TABLE A-1
LAKE ERIE REGULATION - CATEGORY 1 and 2
FOR NIAGARA RIVER STRUCTURE, SERIES "N"
LAKE LEVELS IN FEET, IGLD (1955)

	Basis-of-Comparison	Plan 5N	Plan 10N	Plan 15N	Plan 20N	Plan 25N	Plan 30N
LAKE SUPERIOR							
Mean	600.44	600.42	600.41	600.39	600.38	600.37	600.35
Max	601.93	601.93	601.93	601.93	601.93	601.93	601.92
Min	598.69	598.65	598.65	598.62	598.61	598.62	598.59
Range	3.24	3.28	3.28	3.31	3.32	3.31	3.33
LAKES MICHIGAN-HURON							
Mean	578.27	578.22	578.18	578.14	578.09	578.05	578.01
Max	581.16	581.07	580.99	580.92	580.84	580.75	580.68
Min	575.46	575.44	575.42	575.40	575.38	575.36	575.34
Range	5.70	5.63	5.57	5.52	5.46	5.39	5.34
LAKE ERIE							
Mean	570.76	570.64	570.52	570.40	570.29	570.17	570.05
Max	573.60	573.39	573.18	572.97	572.76	572.53	572.32
Min	568.10	568.04	567.99	567.94	567.89	567.84	567.79
Range	5.50	5.35	5.19	5.03	4.87	4.69	4.53
LAKE ONTARIO (Category 1-With Deviation)							
Mean	244.63	244.61	244.62	244.62	244.62	244.63	244.63
Max	247.37	247.38	247.40	247.43	247.48	247.50	247.54
Min	241.81	241.69	241.59	241.48	241.42	241.38	241.35
Range	5.56	5.69	5.81	5.95	6.06	6.12	6.19
LAKE ONTARIO (Category 2)							
Mean	244.63	244.66	244.69	244.69	244.71	244.71	244.72
Max	247.37	247.37	247.39	247.42	247.43	247.45	247.46
Min	241.81	242.01	242.26	242.17	242.30	242.21	242.25
Range	5.56	5.36	5.13	5.25	5.13	5.24	5.21

regulate the flow from the canal into the river. A control structure in the diversion channel would be used to regulate the outflow from the canal. The structure would be operated so as to effect an average increase in the outflow from Lake Erie whenever the water supply indicator for the upper Great Lakes is at or above normal. Whenever the indicator drops below normal, the discharge through the structure would be reduced to zero.

The volume of water which can pass through the control structure is affected by two factors: (1) the backwater effect of the Niagara River; and (2) the maintenance and use of the canal for navigation (daily operating criteria for the structure are provided in Appendix B, "Regulatory Works"). Applying these two factors to a Squaw Island diversion channel with a capacity of approximately 15,000 cfs results in an effective average annual increase of approximately 9,500 cfs with a monthly distribution as follows:

January	15,300 cfs	July	5,100 cfs
February	15,300 cfs	August	5,100 cfs
March	15,300 cfs	September	7,700 cfs
April 1st half	15,300 cfs	October	7,700 cfs
2nd half	7,700 cfs	November	7,700 cfs
May	7,700 cfs	December 1st half	7,700 cfs
June	5,100 cfs	2nd half	15,300 cfs

In the case of a Squaw Island diversion of approximately 19,000 cfs, an effective average annual increase of 12,000 cfs would be obtained. The monthly distribution related to this case would be as follows:

January	19,200 cfs
February	19,200 cfs
March	19,200 cfs
April - 1st	19,200 cfs
2nd	9,600 cfs
May	9,600 cfs
June	6,400 cfs
July	6,400 cfs
August	6,400 cfs
September	9,600 cfs
October	9,600 cfs
November	9,600 cfs
December - 1st	9,600 cfs
2nd	19,200 cfs

To provide for a range of impacts, costs, and benefits, both of the above plans were applied to the 1900-1976 water supply period. The resulting outflows from Lake Erie under Category 1, for each of these plans, were routed through Lake Ontario in accordance with Regulation Plan 1958-D. Under Category 1, there is no attempt to modify Plan 1958-D to accommodate this increased inflow nor to satisfy the IJC Lake Ontario criteria. The deviations

from plan flow, which were authorized by the International St. Lawrence Board of Control during the period 1960-1976, were employed in this routing, with some adjustments to prevent violation of the downstream low water elevations. The results of these test are shown on Table A-2.

3.4.3 Black Rock Lock Plan (L-Series)

Regulation plans in the series of "L" plans utilize the Black Rock Canal and a modification to the existing lock so that its mitre gates can be opened and closed, with water freely flowing through the lock chamber when required. The structure would be operated in a similar manner to that of the "S" and "N" series plans, i.e., when water supplies to the upper Great Lakes are above normal, increased outflows from Lake Erie would occur; when those supplies are less than normal, the outflow from Lake Erie would be at the preproject rate.

In the use of the Black Rock Canal and Lock, the volume of water which can be passed through the area is affected by the same constraints that control outflows under the "S" series: (1) the backwater effect from the Niagara River; and, (2) the maintenance and use of the canal for navigation. Giving consideration to these facts reduces the volume of water through the lock by about 50%. To provide for a range of impacts, costs, and benefits, two plans in the "L" series were tested to cover the range of outflow from Lake Erie; a plan with a maximum capacity of 16,000 cfs and an effective average annual release of 8,700 cfs, and a plan which utilized a maximum increase of 6,800 cfs with an effective release of 3,700 cfs. The monthly distribution of flows, at low flow, is as follows:

	Plan 6L	Plan 16L
January	6,800 cfs	16,000 cfs
February	6,800 cfs	16,000 cfs
March - 1st	6,800 cfs	16,000 cfs
- 2nd	0	0
April - 1st	0	0
- 2nd	3,400 cfs	8,000 cfs
May	3,400 cfs	8,000 cfs
June	2,300 cfs	5,300 cfs
July	2,300 cfs	5,300 cfs
August	2,300 cfs	5,300 cfs
September	3,400 cfs	8,000 cfs
October	3,400 cfs	8,000 cfs
November	3,400 cfs	8,000 cfs
December - 1st	3,400 cfs	8,000 cfs
2nd	6,800 cfs	16,000 cfs

The resulting outflows, under Category 1, for each of these plans, were routed through Lake Ontario in accordance with Regulation Plan 1958-D. The results of these tests are shown on Table A-3. As in the cases of the "N" and "S" series of plans, there was no attempt to modify Plan 1958-D to accommodate the increased inflow nor to satisfy the IJC Lake Ontario criteria under Category

TABLE A-2
LAKE ERIE REGULATION - CATEGORY 1 and 2
FOR BLACK ROCK CANAL STRUCTURE, SERIES "S"
LAKE LEVELS IN FEET, (IGLD (1955)

	Basis-of-Comparison	Plan 15S	Plan 19S
LAKE SUPERIOR			
Mean	600.44	600.41	600.40
Max	601.93	601.93	601.93
Min	598.69	598.65	598.61
Range	3.24	3.28	3.30
LAKES MICHIGAN-HURON			
Mean	578.27	578.18	578.16
Max	581.16	580.99	580.96
Min	575.46	575.42	575.41
Range	5.70	5.57	5.55
LAKE ERIE			
Mean	570.76	570.53	570.47
Max	573.60	573.18	573.07
Min	568.10	568.02	568.00
Range	5.50	5.16	5.07
LAKE ONTARIO (Category 1-With Deviation)			
Mean	244.63	244.65	244.65
Max	247.37	247.56	247.58
Min	241.81	241.59	241.61
Range	5.56	5.97	5.97
LAKE ONTARIO (Category 2)			
Mean	244.63	244.69	244.72
Max	247.37	247.42	247.43
Min	241.81	242.12	242.15
Range	5.56	5.30	5.28

TABLE A-3
LAKE ERIE REGULATION - CATEGORY 1 and 2
FOR BLACK ROCK CANAL STRUCTURE, SERIES "L"
LAKE LEVELS IN FEET, IGLD (1955)

	Basis-of-Comparison	Plan 6L	Plan 16L
LAKE SUPERIOR			
Mean	600.44	600.43	600.42
Max	601.93	601.93	601.93
Min	598.69	598.68	598.66
Range	3.24	3.25	3.27
LAKES MICHIGAN-HURON			
Mean	578.27	578.24	578.21
Max	581.16	581.09	581.07
Min	575.46	575.45	575.42
Range	5.70	5.64	5.65
LAKE ERIE			
Mean	570.76	570.67	570.61
Max	573.60	573.45	573.40
Min	568.10	568.07	568.02
Range	5.50	5.38	5.38
LAKE ONTARIO (Category 1-With Deviation)			
Mean	244.63	244.64	244.61*
Max	247.37	247.39	247.38
Min	241.81	241.74	241.69
Range	5.56	5.65	5.69
LAKE ONTARIO (Category 2)			
Mean	244.63	244.66	244.69*
Max	247.37	247.34	247.39
Min	241.81	242.04	242.26
Range	5.56	5.30	5.13

* Results interpolated from (N) results - Table A-1

1. These plans also required some minor adjustments in application of the deviations from Plan 1958-D by the International St. Lawrence River Board of Control, to preclude violation of the downstream low water elevations.

3.5 Category 2 - Modified Lake Ontario Regulation Plan 1958-D

As noted in paragraph 3.1, plans under Category 2 consist of modifications to the operational rules of Lake Ontario Regulation Plan 1958-D to accommodate limited regulation of Lake Erie, and to satisfy the IJC criteria for the regulation of Lake Ontario to the same degree as occurred under the development of Plan 1958-D and under actual operation of Plan 1958-D since 1960. The purpose of these plans is to establish the feasibility of combined Lake Erie-Lake Ontario regulation; hence, one Lake Erie plan under each series (to cover the total range of increases in outflow) has been selected for consideration under Category 2. The plans are those designated as 25N (which increases the outflow form Lake Erie by 25,000 cfs), 15S (which increases the outflow from Lake Erie by 15,400 cfs, with an effective average release of 9,600 cfs), and 6L (which increases the outflow from Lake Erie by 6,800 cfs, with an effective average release of 3,700 cfs).

Regulation of Lake Ontario under Plan 1958-D consists of the selection of an outflow from a basic rule curve and a comparison of that outflow with a series of outflow limitations. If the selected outflow is greater than the minimum limitation and less than the maximum limitation, it is the outflow released from the lake. If, however, it falls outside the limitation, the limitation will govern the flow to be released. Under Category 2 these limitations ("I", "P", "M", "J" and "L") have been modified to accomplish the study objectives. Modifications to these limitations are discussed in the following paragraphs, and results of applying the modifications are presented on Tables A-4, A-5, and A-6.

3.5.1 "I" Limitation

The "I" limitation under Plan 1958-D relates to the maximum permissible release of water from Lake St. Louis during the last half of December. This limitation was incorporated into Plan 1958-D to provide for ice formation under a proposed plan for the Lachine Rapids power development. This development has not occurred. As a result, the International St. Lawrence River Board of Control has, on numerous occasions, waived this limitation under actual operation without adverse impact. Under Plans 25N, 15S and 6L, this restriction on flow during the last half of December has been waived for the total study period (1900-1976).

3.5.2 "P" Maximum Flow Limitation

This limitation restricts the regulated outflow to an amount that would occur if preproject channel conditions existed. This limitation on flow has been incorporated into the plans so as not to aggravate flooding conditions in the Lake St. Louis-Montreal Harbour areas during the ice-break-up period and during the annual flood discharge of the Ottawa River. The "P" flow limitation is applicable from February to mid-April, and from mid-April to the

end-of-July for those periods when the outflow from Lake St. Louis exceeds 345,000 cfs. Studies of this limitation under actual operation indicate that employment of the 345,000 cfs value is conservative. Hence, a value of 380,000 cfs was adopted for use in Plans 25N, 15S, and 6L under Category 2.

3.5.3 "M" Minimum Flow Limitation

IJC Criterion (e) for the regulation of Lake Ontario, states;

> "Consistent with other requirements, the minimum regulated monthly outflows from Lake Ontario shall be such as to secure the maximum dependable flow for power,"

Criterion (j) states;

> "The regulated level of Lake Ontario on 1 April shall not be lower than elevation 242.77. The regulated monthly mean level of the lake from 1 April to 30 November shall be maintained at or above elevation 242.77"

To satisfy these criteria under Category 2, some adjustment to Plan 1958-D minimum flow was required. The minimum flow employed in Plans 25N, 15S and 6L are shown in the following table.

TABLE A-4
MINIMUM OUTFLOWS
Category 2
(in TCFS)

	Plan 1958-D	Plan 25N	Plan 15S	Plan 6L
Jan	210	202	204	205
Feb	207	200	200	202
Mar	204	195	196	195
Apr	188	188	188	188
May	188	188	188	188
Jun	190	190	190	193
Jul	193	190	190	200
Aug	193	195	195	201
Sep	193	202	202	202
Oct	193	202	204	205
Nov	198	202	204	205
Dec	210	202	204	205

3.5.4 "J" Outflow Limitation

To restrict the variation in outflow from one quarter-month to the next, Plan 1958-D limited changes between regulation periods to 20,000 cfs. Under Category 2, the limit has been raised to 45,000 cfs. The need for the greater flexibility is due to the sometimes sudden changes in water supply, caused by the regulation technique being employed on Lake Erie.

3.5.5 "L" Outflow Limitation

To provide stipulated depths and velocities for navigation and power, channel excavations have been provided in the St. Lawrence River. To keep the regulated Lake Ontario outflows and resulting levels and velocities in the river consistent with these channel excavations, restrictions have been placed on flow releases during various periods of the year. These restrictions are shown on Figure A-4 and are applied under procedural application of Plan 1958-D. However, under actual operation under Plan 1958-D (since 1960), some of these restrictions were relaxed to a point where the stipulated maximum channel velocity of 4 ft/sec was exceeded, but the minimum navigation depth was not. Employing these operational flows as a guide, modifications were made to the procedural values shown on Figure A-4 to accommodate for the increased inflow caused by regulation of Lake Erie under Plans 25N, 15S and 6L. As shown on Figure A-5, the resulting modifications do not affect the lower portion of the "L" limitation curve. Hence, under Category 2, there is no requirement for excavation in the International Rapids area to satisfy the navigation and power requirements for river profiles.

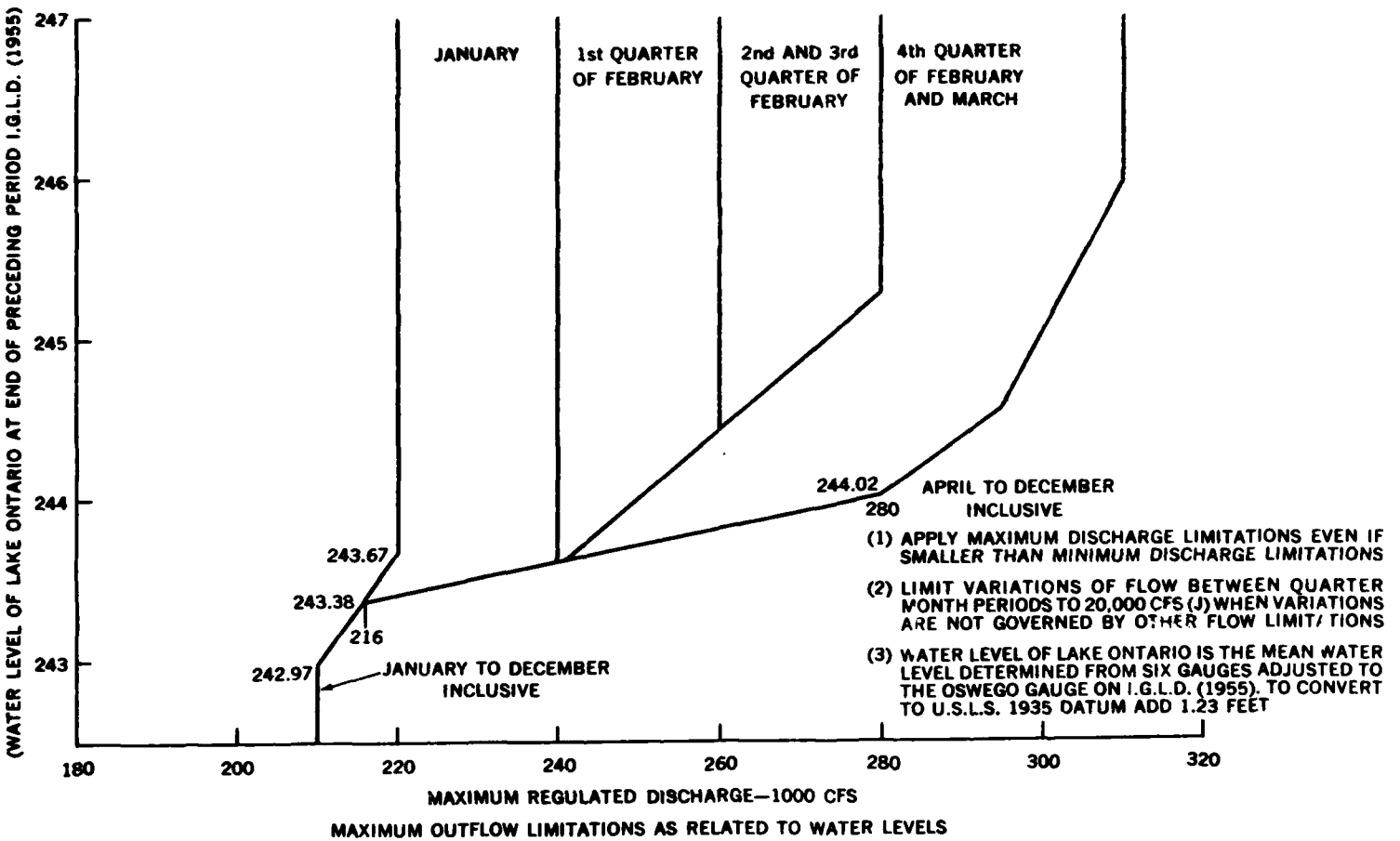
3.6 Category 3 - Modified Lake Ontario Plan 1958-D

As noted in paragraph 3.1, Category 3 consists of the same plans for Lake Erie regulation employed in Category 2, with the rules of Plan 1958-D modified and the St. Lawrence River channels enlarged to accommodate Lake Erie regulation. Category 3 differs from Category 2 in that the resulting Lake Ontario levels and outflows are to satisfy the criteria as written in the "Orders and Supplementary Orders of Approval" over the entire 1900-1976 test period. As in the case of Category 2, modification to Plan 1958-D consisted of making changes to the "I", "P", "M", "J" and "L" limitations to accommodate Lake Erie regulation and the water supplies that occurred over the period 1900-1976. It should be noted that these limitations were developed based on the high supplies prior to 1954. (The St. Lawrence Seaway and Power Project, completed in 1958, was designed and built to accommodate the highest historic supply up to 1954.) Some revision to the limitations would have been necessary to satisfy the 1973 highs, under Plan 1958-D.

To separate the necessary modifications to Plan 1958-D caused by Lake Erie regulation from those which were caused by the abnormally low water supplies of the 1960's and high water supplies of the 1970's, an adjusted basis-of-comparison was developed. The following paragraphs discuss the necessary changes to Plan 1958-D to satisfy the IJC criteria and to accommodate Lake Erie regulation under Category 3. Section 3.7 covers the data developed for comparison purposes under that plan.

3.6.1 "I" Limitation

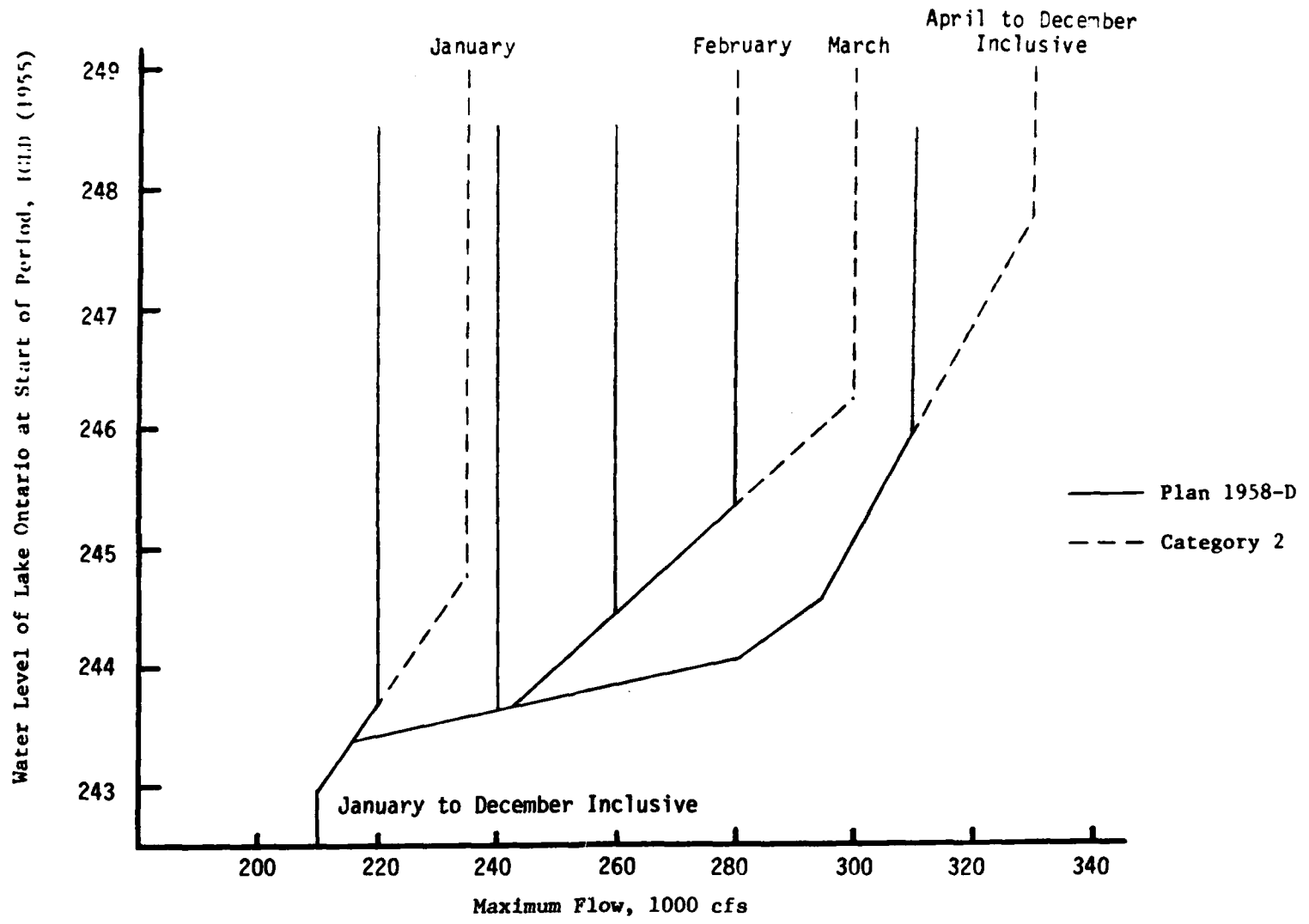
As noted in paragraph 3.5.1, the "I" limitation under Plan 1958-D relates to the maximum release of water from Lake St. Louis during the last half of December. This limitation has been waived on numerous occasions by the International St. Lawrence River Board of Control and was not employed in the testing of the Category 3 plans.



MAXIMUM OUTFLOW LIMITATIONS AS RELATED TO WATER LEVELS

FIGURE A-4

REGULATION OF LAKE ONTARIO PLAN 1958-D
"L" LIMITATION CURVE



REGULATION OF LAKE ONTARIO
PLAN 1958-D AND AS MODIFIED FOR CATEGORY 2

Figure A-5

3.6.2 "P" Maximum Flow Limitation

Under Category 2 modifications to Plan 1958-D, the "P" limitation was applied during the period from mid-April to the end-of-July only when the outflow from Lake St. Louis exceeded 380,000 cfs, rather than the presently used value of 345,000 cfs. Under Category 3, the 345,000 cfs application limitation was retained for the total test period (1900-1976). This change was due to the difference in objectives between Category 2 and Category 3. Increasing the flow from 345,000 cfs to 380,000 cfs when the "P" limitation applies would not better satisfy the criteria during the high water supply periods of the 1970's. However, under Category 3, it was necessary to add 15,000 cfs to the limiting control numbers employed in Plan 1958-D to duplicate conditions which occurred in the 1970's.

The "P" limitation was incorporated into Plan 1958-D to restrict Lake Ontario releases to preproject flows in order to satisfy criteria (c) and (d) of the Commission's Orders of Approval. By increasing the "P" limitation, as was done in Category 3, it would appear that these criteria would be violated. However, the channel modifications also undertaken in Category 3 were designed to provide a reduction in river levels sufficient to compensate for the 15,000 cfs increase.

3.6.3 "M" Minimum Flow Limitation

Paragraph 3.5.3 notes the minimum outflow criterion to be satisfied by any plan of regulation. Listed below are the minimum flows for each plan developed under this study category to satisfy these requirements.

TABLE A-5
MINIMUM OUTFLOWS
Category 3
(in TCFS)

	Plan 25N	Plan 15S	Plan 6L
Jan	200	202	203
Feb	200	200	200
Mar	195	195	196
Apr	188	188	188
May	188	188	188
Jun	190	190	190
Jul	190	190	195
Aug	195	195	197
Sep	200	202	202
Oct	200	202	203
Nov	200	202	203
Dec	200	202	203

3.6.4 "J" Outflow Limitation

Category 3 employs the same restriction on outflow changes between regulation periods as developed for Category 2 (45,000 cfs).

3.6.5 "L" Outflow Limitation

Figure A-6 shows the modified "L" limitation curve employed under Plan 1958-D. Superimposed on this plate are the modified conditions for Plans 25N, 15S and 6L. The resulting modifications provide for satisfaction of the criteria for the regulation of Lake Ontario over the entire test period (1900-1976). The changes cannot be totally attributed to Lake Erie regulation, but are also due in part to the water supplies of the 1970's, which exceeded those used to develop Plan 1958-D. The separation of the two effects (that which is due to Lake Erie regulation versus that due to the high water supplies) is further discussed in Section 4.3.

3.7 Adjusted Basis-of-Comparison

To provide data under the basis-of-comparison for use with Category 3 plans, Plan 1958-D was modified to accommodate the low and high water supplies of the 1960's and 1970's, respectively, and to satisfy the IJC criteria for the regulation of Lake Ontario. These modifications were applied to the total study period, 1900-1976, and are necessary so that the benefit/cost ratio attributable to Lake Erie regulation can be separated from that obtained through satisfaction of the IJC Orders of Approval for Lake Ontario.

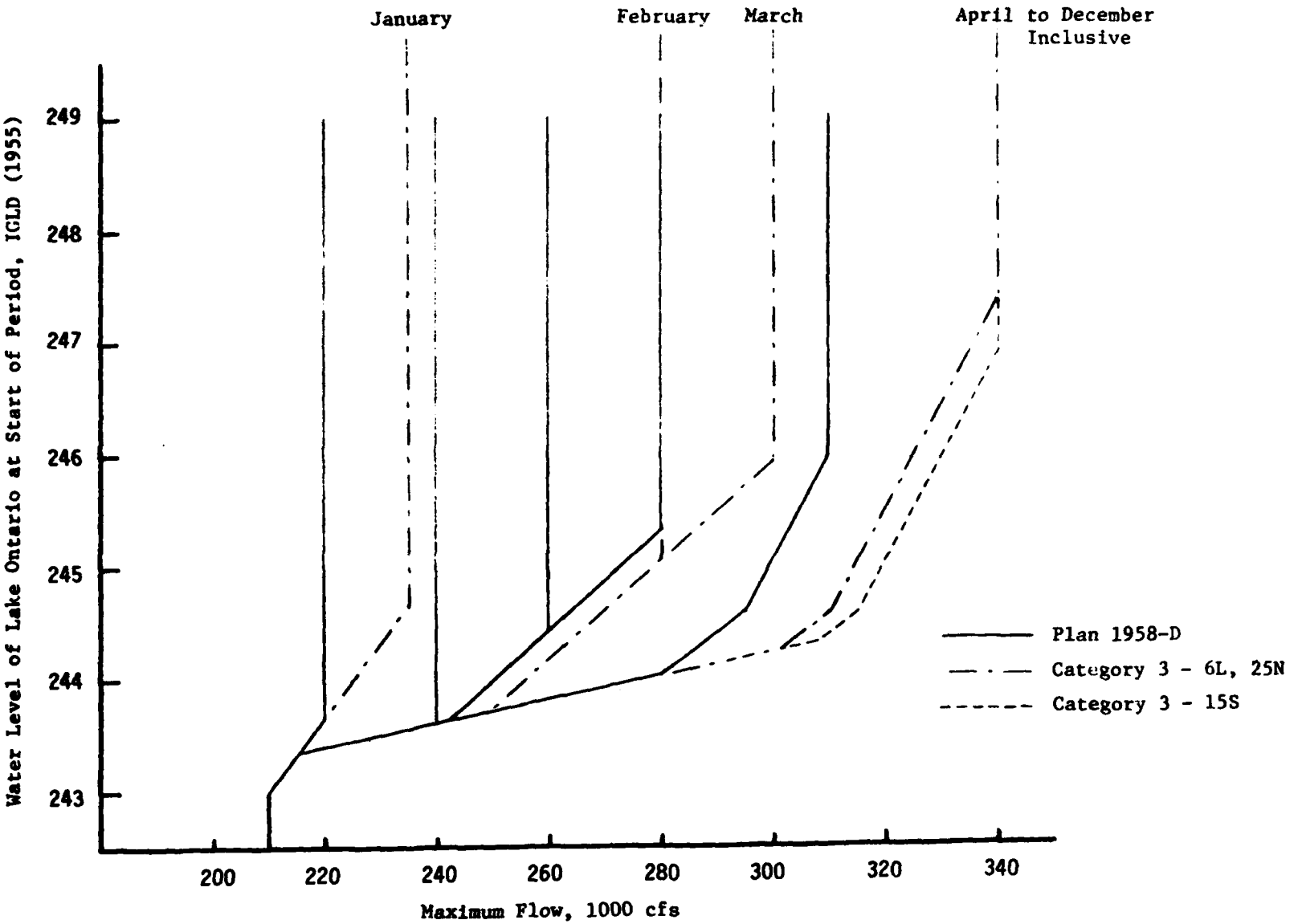
These adjustments reflect, not only the changes required to accommodate the extreme water supplies, but also those which are occasioned by regulation of Lake Superior under Plan 1977. Adjustments to Plan 1958-D under the basis-of-comparison are described in the following sections.

3.7.1 "M" Minimum Flow Limitation

Listed below are the minimum flows under Plan 1958-D, and under the modified Plan 1958-D. The reduction in minimum flow under the adjusted basis-of-comparison was necessary to accommodate the low water supplies of the 1960's and satisfy the 1 April level under Criterion (j) of the Supplementary Orders of Approval.

TABLE A-6
MINIMUM OUTFLOWS
(in TCFS)

Month	Basis-of-Comparison	Adjusted Basis-of-Comparison
Jan	210	203
Feb	207	200
Mar	204	196
Apr	188	188
May	188	188
Jun	190	190
Jul	193	195
Aug	193	197
Sep	193	202
Oct	193	203
Nov	198	203
Dec	210	203



REGULATION OF LAKE ONTARIO
PLAN 1958-D AND AS MODIFIED FOR CATEGORY 3

Figure A-6

3.7.2 "I" Limitation

The "I" limitation, as noted, has been waived on numerous occasions under actual operation. Under the adjusted basis-of-comparison, this limitation on release during the last half of December has not been employed.

3.7.3 "J" Limitation

Under Plan 1958-D, the restriction on changes in flow between regulation periods is limited to 20,000 cfs. Under the adjustment employed herein, this value has been changed to 45,000 cfs.

3.7.4 "L" Maximum Outflow Limitation

The St. Lawrence Seaway and Power Project Channels, completed in 1958, were designed and built to accommodate the historic water supplies up through 1954 and satisfy the IJC criteria for the regulation of Lake Ontario. The water supplies during the mid-1960's and early 1970's exceeded the historic range employed in the Plan 1958-D design. Hence, certain revisions were necessary to the "L" limitation curve of Plan 1958-D to accommodate these water supplies and satisfy the criteria to the same degree as under the original test of Plan 1958-D. Figure A-7 shows the modified "L" limitation curve employed in the adjusted basis-of-comparison.

3.7.5 "P" Maximum Flow Limitation

During certain periods of the year, the outflow from Lake Ontario is restricted under Plan 1958-D to preproject flows, in order to satisfy criteria (c) and (d) of the Commission's Order of Approval. These criteria are related to the annual spring break-up in Montreal Harbour and the annual flood discharge from the Ottawa River. To duplicate conditions that occurred in the 1970's, it was necessary to increase the limiting control numbers employed in Plan 1958-D by 15,000 cfs when the outflow from Lake St. Louis, during the preceding quarter, exceeds 345,000 cfs. The point of application in the adjusted basis-of-comparison is the same as under Plan 1958-D.

3.7.6 "P" Minimum Flow Limitation

No change was made in this feature under the adjusted basis-of-comparison from that employed in the basis-of-comparison.

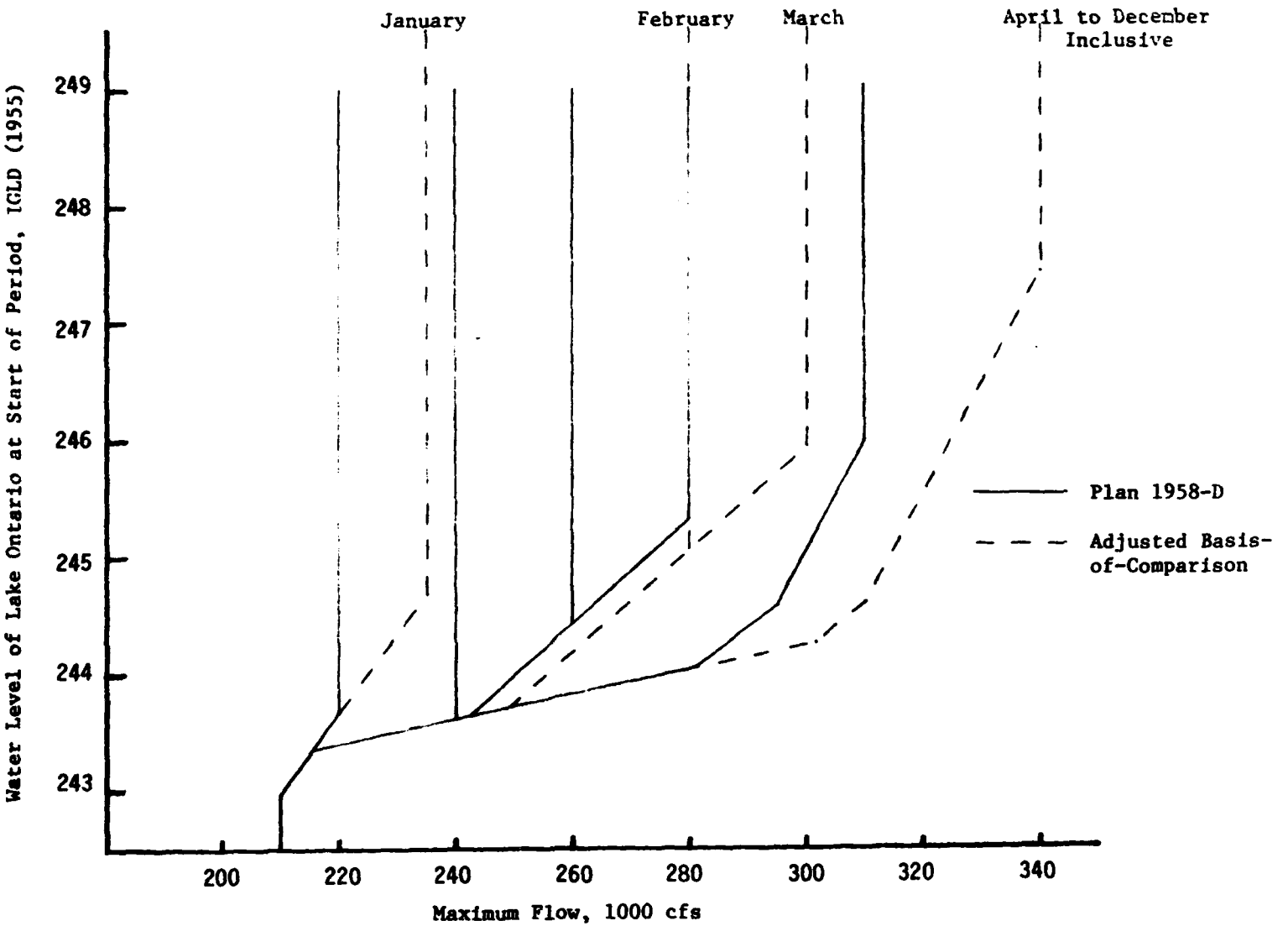


Figure A-7

REGULATION OF LAKE ONTARIO
PLAN 1958-D AND AS MODIFIED FOR ADJUSTED BASIS-OF-COMPARISON

Section 4

EVALUATION OF REGULATION PLANS

4.1 General

The two primary hydrologic factors evaluated in the report are lake levels and outflows. Analysis of these two factors includes the consideration of their maximum, mean and minimum monthly values, ranges, duration and seasonal distribution. Various criteria expressed in these hydrologic terms are used to evaluate the regulation plans developed herein. These criteria reflect the IJC "Orders of Approval" on the regulated lakes. For the currently non-regulated lakes, similar criteria were developed by the investigators. The evaluation involves the determination of the degree to which each regulation plan meets such criteria in comparison to the basis-of-comparison. The data employed are those resulting from the test of the regulation plan over the 1900-1976 water supply period. The following subsections discuss the hydrologic evaluation of selected plans with respect to the criteria and objectives for regulation. Presented are the Category 1 evaluation for all lakes and the Category 2 and 3 evaluations for Lake Ontario.

4.2 Category 1 Plans

Category 1 Plans consist of limited regulation of Lake Erie, with present channel limitation of the St. Lawrence River, and Lake Ontario regulated in accordance with Plan 1958-D, with discretionary deviations as they actually occurred.

4.2.1 Lake Superior

Criterion (a): The Commission's 1979 Orders require that Lake Superior be maintained so as not to exceed 602.0 feet nor fall below 598.4 feet.

The maximum and minimum monthly mean levels of Lake Superior under each of the plans selected for detailed evaluation are shown on Table A-7. Of considerable importance with respect to this criterion is the frequency of occurrence of high and low levels. Tables A-8 and A-9 compare the frequency under each of the plans with the basis-of-comparison.

Table A-7 shows that regulation of Lake Erie would not cause a marked impact on the maximum level. In fact, the maximum level is the same as that occurring under the basis-of-comparison. In all cases, the criterion "not to exceed 602.0" has been satisfied. In addition, Table A-7 shows that although the extreme low levels have been lowered somewhat by the regulation of Lake Erie, they have not been lowered below 598.4 feet.

TABLE A-7

LAKE ERIE REGULATION - CATEGORY 1
Lake Levels in Feet, IGLD (1955)

	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
LAKE SUPERIOR				
MEAN	600.44	600.43	600.41	600.37
MAX	601.93	601.93	601.93	601.93
MIN	598.69	598.68	598.65	598.62
RANGE	3.24	3.25	3.28	3.31
LAKES MICHIGAN-HURON				
MEAN	578.27	578.24	578.18	578.05
MAX	581.16	581.09	580.99	580.75
MIN	575.46	575.45	575.42	575.36
RANGE	5.70	5.64	5.57	5.39
LAKE ERIE				
MEAN	570.76	570.67	570.53	570.17
MAX	573.60	573.45	573.18	572.53
MIN	568.10	568.07	568.02	567.84
RANGE	5.50	5.38	5.16	4.69
LAKE ONTARIO (Category 1-with deviation)				
MEAN	244.63	244.64	244.65	244.63
MAX	247.37	247.39	247.56	247.50
MIN	241.81	241.74	241.59	241.38
RANGE	5.56	5.65	5.97	6.12

TABLE A-8

MONTHLY MEAN WATER LEVELS OF LAKE SUPERIOR
1900-1976

NUMBER OF OCCURRENCES ABOVE LEVEL SHOWN

Monthly Mean Level	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
602.0	0	0	0	0
601.9	1	1	1	1
601.8	1	1	1	1
601.7	2	2	2	2
601.6	9	8	5	4
601.5	18	19	16	11
Maximum	601.93	601.93	601.93	601.93

TABLE A-9

MONTHLY MEAN WATER LEVELS OF LAKE SUPERIOR
1900-1976

NUMBER OF OCCURRENCES BELOW LEVEL SHOWN

ALL MONTHS

Monthly Mean Level	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
600.0	211	218	225	247
599.5	49	49	56	61
599.0	6	7	7	9
598.5	0	0	0	0
598.0	0	0	0	0
Minimum	598.69	598.68	598.65	598.62

APRIL-NOVEMBER

600.0	85	90	93	103
599.5	18	18	23	25
599.0	2	2	2	3
598.5	0	0	0	0
598.0	0	0	0	0
Minimum	598.70	598.69	598.66	598.63

Tables A-8 and A-9 emphasize the above point. Table A-8 shows a reduction in the frequency of occurrence of all stages above 601.6 feet under all three plans, when compared to the basis-of-comparison. This should provide a benefit to the coastal zone interests on Lake Superior. Table A-9 shows an increase in the frequency of levels below elevation 600.0 feet (LWD on Lake Superior). The magnitude of lowering becomes greater as the magnitude of increased outflow from Lake Erie becomes greater (6L vs. 25N). The lowering would have an adverse impact on navigation and power.

Criterion (b): The Commission's Orders specify, that in order to guard against unduly high levels of water in the lower St. Marys River, the excess discharge at any time over and above that which would have occurred at a similar level on Lake Superior prior to 1887, shall be restricted so that elevation of the water surface immediately below the locks shall not be greater than 582.9 feet.

In the test of the Lake Superior portion of the plans presented herein, over the period 1900-1976, the maximum stage at the U.S. Slip gage, below the lock was as shown on Table A-10. Table A-10 shows that criterion (b) has been satisfied by all three plans.

TABLE A-10
MAXIMUM STAGE - U.S. SLIP

	Elevation
Basis-of-Comparison	582.32
Plan 6L	582.28
Plan 15S	582.24
Plan 25N	582.09

The Commission's 1979 Order specifies that whenever the monthly mean level of the lake is less than 600.5 feet, the total discharge permitted shall be no greater than that which would have been discharged at the prevailing stage of Lake Superior prior to 1887.

This criterion was not evaluated since it was a criterion developed for operational purposes and did not impact on the theoretical application of the plan. However, Tables A-9 and A-13 show that this criterion, if evaluated, would have been satisfied to approximately the same degree as under the basis-of-comparison.

Criterion (c): The maximum open-water (May-November) limitation on outflow from Lake Superior is equivalent to the discharge capacity of the Compensating Works, plus 65,000 cfs.

This maximum outflow limitation was also applicable under the basis-of-comparison. All plans presented employ this maximum summer outflow and therefore this criterion has been satisfied. Table A-11 compares the results of the plans with those of the basis-of-comparison.

The table shows that the maximum flow out of Lake Superior under the three plans being evaluated are identical to that which occurred under the basis-of-comparison. The table further shows a reduction in the frequency of occurrence of these high flows.

Criterion (d): The maximum winter outflow (December-April) from Lake Superior shall not be greater than 85,000 cfs.

This maximum outflow limitation was applicable under the basis-of-comparison. All plans presented employ this maximum winter outflow and therefore this criterion has been satisfied to the same degree as under the basis-of-comparison. Table A-12 compares the results of the plans with those of the basis-of-comparison. The table shows that the maximum flow out of Lake Superior under the three plans being evaluated are essentially the same as under the basis-of-comparison. However, it should be noted that under Plan 25N there is an increase in the frequency of occurrence of these high flows.

Criterion (e): The minimum outflow from Lake Superior shall not be less than 55,000 cfs.

The minimum outflow from Lake Superior under all three plans has been set at 55,000 cfs. Hence, the criterion has been satisfied. Table A-13 compares the frequency of flows below 65,000 cfs. The table shows a decrease in the frequency of low flow under two of the plans (Plan 15S and Plan 25N) which will be beneficial to power produced on the St. Marys River.

4.2.2 Lakes Michigan-Huron

The following paragraphs give the evaluation of effects of the three plans presented herein on Lakes Michigan-Huron, employing criteria formulated by the Board for this purpose:

Criterion (a): Consistent with other requirements, reduce the frequency of occurrence of high Lakes Michigan-Huron levels.

Table A-7 indicates that all three regulation plans reduce the maximum stage of Lakes Michigan-Huron, in comparison to that which occurred under the basis-of-comparison. Table A-14 compares the frequency of occurrence above elevation 579.0 feet. All plans show a reduction in the frequency, with maximum reduction occurring under Plan 25N. All plans are an improvement over the basis-of-comparison, in light of the objective stated for the regulation of Lake Erie.

TABLE A-11

MONTHLY MEAN OUTFLOW FROM LAKE SUPERIOR
MAY-NOVEMBER 1900-1976
NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN

Monthly Mean Flow (Thousands of cfs)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
125	0	0	0	0
120	3	3	3	3
115	43	43	40	37
110	68	68	66	64
105	94	94	92	84
100	133	128	125	126
Maximum	123,000	123,000	123,000	123,000

TABLE A-12

MONTHLY MEAN OUTFLOW FROM LAKE SUPERIOR
DECEMBER-APRIL 1900-1976
NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN

Monthly Mean Flow (Thousands of cfs)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
85	3	3	3	5
84	8	7	7	12
83	11	11	11	16
82	14	14	14	19
81	27	27	26	30
80	42	42	41	47
Maximum	86,000	86,000	86,000	87,000

TABLE A-13

MONTHLY MEAN OUTFLOW FROM LAKE SUPERIOR
1900-1976
NUMBER OF OCCURRENCES BELOW OUTFLOW SHOWN

Monthly Mean Outflow (Thousands of cfs)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
65,000	155	159	148	152
58,000	155	159	148	152
55,000	0	0	0	0

TABLE A-14

MONTHLY MEAN WATER LEVELS OF LAKES MICHIGAN-HURON
1900-1976
NUMBER OF OCCURRENCES ABOVE LEVEL SHOWN

Monthly Mean Level (Feet)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
581.4	0	0	0	0
581.0	4	2	0	0
580.6	17	13	11	6
580.2	35	33	29	18
579.8	69	65	51	37
579.4	144	139	125	83
579.0	256	244	224	184
Maximum Level	581.16	581.09	580.99	580.75

Criterion (b): Consistent with other requirements, reduce the frequency of occurrence of low Lakes Michigan-Huron levels, especially during the navigation season (April-November).

Table A-15 indicates that all three plans reduce the minimum stage and increase the frequency of occurrence of levels below LWD, in comparison to the basis-of-comparison. Even though the magnitude of the lowering is small, the plans have an adverse impact when compared to the objectives for Lake Erie regulation.

4.2.3 Lake Erie

The following paragraphs give the evaluation of effects of the various plans on Lake Erie, employing criteria formulated by the Board for this purpose.

Criterion (a): Consistent with other requirements, reduce the frequency of occurrence of high Lake Erie levels.

Table A-16 indicates that all three plans lower the maximum level and reduce the frequency of occurrence of high levels. This reduction amounts to 1.07 feet under Plan 25N; 0.42 foot under Plan 15S and 0.15 foot under Plan 6L. The frequency of occurrence of high levels (above 572.0 feet) was reduced by 85% under Plan 25N; 46% under 15S; and 18% under 6L. Hence, this criterion has been satisfied by all plans evaluated.

Criterion (b): Consistent with other requirements, reduce the frequency of occurrence of low Lake Erie levels, especially during the navigation season (April-November).

Table A-17 shows that the minimum stage would be reduced and the frequency of occurrence of low levels would be increased under all three plans, in comparison to the basis-of-comparison. The table shows a lesser impact during the navigation season than during the all-months period. However, even though this lowering is small in magnitude, the plans have not satisfied the criterion, in comparison with the conditions existing under the basis-of-comparison.

4.2.4 Lake Ontario

The criteria and supplementary requirement stated hereunder have been extracted directly from the 1963 report entitled "Regulation of Lake Ontario Plan 1958-D", by the International St. Lawrence River Board of Control to the International Joint Commission. These criteria and the tests of regulation plans by that Board relate to the 1860-1954 period. For evaluation purposes in this study, as noted in Section 2.2, the period of study is 1900-1976, and the basis-of-comparison includes the current operating plan (Plan 1958-D) as designed for the period 1900-1960 and as operated thereafter.

TABLE A-15

MONTHLY MEAN WATER LEVELS OF LAKES MICHIGAN-HURON
1900-1976
NUMBER OF OCCURRENCES BELOW LEVEL SHOWN

APRIL-NOVEMBER

Monthly Mean Level (Feet)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
576.8 (LWD)	40	44	48	59
576.4	14	14	14	16
576.0	4	5	6	7
575.6	0	0	1	1
575.2	0	0	0	0
Minimum	575.62	575.61	575.58	572.52

ALL-MONTHS

576.8 (LWD)	91	96	101	120
576.4	38	38	39	47
576.0	16	17	18	21
575.6	4	5	6	8
575.2	0	0	0	0
Minimum	575.46	575.45	575.42	575.36

TABLE A-16

MONTHLY MEAN WATER LEVELS OF LAKE ERIE
1900-1976
NUMBER OF OCCURRENCES ABOVE LEVEL SHOWN

Monthly Mean Level (Feet)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
573.0	16	11	3	0
572.8	27	18	11	0
572.6	37	29	14	0
572.4	55	39	26	5
572.2	78	63	37	12
572.0	108	89	58	16
Maximum	573.60	573.45	573.18	572.53

TABLE A-17

MONTHLY MEAN WATER LEVELS OF LAKE ERIE
1900-1976
NUMBER OF OCCURRENCES BELOW LEVEL SHOWN

APRIL-NOVEMBER

Monthly Mean Level (Feet)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
569.0	8	9	11	22
568.8	4	5	5	12
568.6 LWD	3	3	3	6
568.4	1	1	1	1
568.2	0	0	0	0
Minimum	568.32	568.30	568.28	568.24

ALL-MONTHS

569.0	30	33	37	68
568.8	24	25	27	49
568.6 LWD	15	16	18	24
568.4	4	4	5	7
568.2	1	1	1	2
568.0	0	0	0	1
Minimum	568.09	568.07	568.02	567.84

In the following paragraphs each criterion and supplementary requirement of regulation is stated, followed by a discussion with tables showing the degree to which each plan fulfills these requirements in comparison with the current operating plan. It should be noted that under Category I there is no attempt to modify Plan 1958-D to accommodate the increased inflow due to Lake Erie regulation.

Criterion (a): The regulated outflow from Lake Ontario from April 1 to December 15 shall be such as not to reduce the minimum level of Montreal Harbour below that which would have occurred in the past with the supplies to Lake Ontario since 1860 adjusted to a condition assuming a continuous diversion out of the Great Lakes basin of 3,100* cubic feet per second at Chicago and a continuous diversion into the Great Lakes basin annually of 5,000 cubic feet per second from the Albany River basin.

Lake St. Louis outflows are representative of the levels of Montreal Harbour. A comparison of the minimum monthly mean outflows from Lake St. Louis with basis-of-comparison data will indicate the degree to which the criterion has been satisfied. To assess the effect of regulation on low water levels of Montreal Harbour, it has been customary in the studies conducted by the International St. Lawrence River Board of Control to compare the frequency of occurrence of outflows from Lake St. Louis below 230,000 cfs.

Table A-18 shows that the minimum outflow from Lake St. Louis under all three plans is the same (except for 25N) as that which occurred under the basis-of-comparison. The table also shows a comparison of the frequency of occurrence of low flows. The table shows a slight increase in low flow below 230,000 under Plan 15S and Plan 25N, however, at flows less than 225,000 cfs the frequency of occurrence under all three plans is practically the same as under the basis-of-comparison; however, the criterion has not been satisfied to the same degree as under current operating conditions.

Criterion (b): The regulated winter outflows from Lake Ontario from December 15 to March 31 shall be as large as feasible and shall be maintained so that the difficulties of winter operation are minimized.

Table A-19 shows that the minimum outflow under all three plans are the same as occurred under the basis-of-comparison and thus the criterion has been satisfied.

Criterion (c): The regulated outflow from Lake Ontario during the annual spring break-up in Montreal Harbour and in the river downstream shall not be greater than would have occurred assuming supplies of the past as adjusted.

*Changed to 3,200 cfs in this study.

TABLE A-18

MONTHLY MEAN OUTFLOWS FROM LAKE ST. LOUIS
APRIL 1-DECEMBER 15 (1900-1976)
NUMBER OF OCCURRENCES BELOW OUTFLOW SHOWN

Outflow (Thousands of cfs)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
230	27-1/2	27-1/2	29	31-1/2
225	15	15	15	16
220	9-1/2	9-1/2	9-1/2	8-1/2
215	5	5	5	6
210	0	0	0	0
205	0	0	0	0
200	0	0	0	0
195	0	0	0	0
Minimum	212	212	212	211

TABLE A-19

WINTER OUTFLOWS FROM LAKE ONTARIO (1900-1976)
(IN THOUSANDS OF CUBIC FEET PER SECOND)

	Basis-of-Comparison			Plan 6L			Plan 15S			Plan 25N		
PERIOD	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.
December 15-31	279	188	226	282	188	226	280	188	227	280	188	226
January	250	185	217	250	185	217	250	185	217	250	185	216
February	285	182	228	285	182	229	285	182	229	285	182	228
March	300	179	234	300	179	234	300	179	235	300	179	234

In applying this criterion, consideration must be given to the ice breaking activities which take place each year in the St. Lawrence Ship Channel. Past records show that the annual breakup in Montreal Harbour generally has occurred during the first half of April. The ice breaking activities in recent years have tended to modify the application of this criterion, either by advancing the time of ice breakup into March or by minimizing the serious flooding which can result at the time of the breakup. Table A-20 compares the results obtained under the various plans with the basis-of-comparison.

Table A-20 shows that the maximum outflow from Lake Ontario under all three plans is the same as occurred under the basis-of-comparison. However, the table also shows that there is a slight increase in frequency of occurrence of flows above 250,000. Hence, this criterion has not been satisfied to the same degree as under the basis-of-comparison.

Criterion (d): The regulated outflow from Lake Ontario during the annual flood discharge from the Ottawa River shall not be greater than the discharge that would have occured assuming supplies of the past as adjusted.

This criterion is included to protect the riparian interests on Lake St. Louis, in Montreal Harbour, and on the river downstream. Past records show that the maximun level of Lake St. Louis each year, influenced to a significant extent by the flood flow of the Ottawa River, has occurred about 60 percent of the time in the month of May, with the remainder of the occurrences of seriously high conditions occurring in April and June. Table A-21 indicates the extent to which this criterion has been met by the various plans presented herein.

Table A-21 which compares the outflows under the three plans during the critical periods with those of the basis-of-comparison, shows that the maximum outflows from Lake Ontario under all conditions is the same. However, the table does show a slight reduction in the maximum outflow from Lake St. Louis under Plans 15S and 25N from that which occurred under the basis-of-comparison during June. In general, with reference to occurrence of high flows from Lake St. Louis, the table shows a slight increase in flows from 380,000 to 410,000 cfs, but above that point very little change from the basis-of-comparison. From the table it can be concluded that, in general, this criterion has been satisfied by the three plans to the same degree as by the basis-of-comparison.

Criterion (e): Consistent with other requirements, the minimum regulated outflows from Lake Ontario shall be such as to secure the maximum dependable flow for power.

Table A-22 shows that the minimum flows under all three plans are the same as occurred under the basis-of-comparison. Hence, this criterion has been satisfied to the same degree as under the basis-of-comparison.

TABLE A-20

MEAN MARCH OUTFLOWS FROM LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

Outflow (Thousands of cfs)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
250	19	22	22	23
260	11	13	14	13
270	7	8	8	8
280	4	4	4	4
290	2	2	2	2
Maximum	300	300	300	300

MEAN FIRST HALF APRIL OUTFLOW FROM LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

250	28	28	30	30
260	17	17	21	20
270	11	11	14	14
280	6	8	9	9
290	5	6	6	6
Maximum	318	318	318	318

TABLE A-21

MONTHLY MEAN OUTFLOWS FROM LAKE ONTARIO - AND LAKE ST. LOUIS
APRIL, MAY AND JUNE (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

LAKE ONTARIO

Outflow (Thousands of cfs)	Basis-of-Comparison			Plan 6L			Plan 15S			Plan 25N		
	APR	MAY	JUN	APR	MAY	JUN	APR	MAY	JUN	APR	MAY	JUN
260	22	31	30	24	31	30	26	31	31	25	29	33
270	12	24	27	12	24	27	16	25	28	17	25	27
280	9	15	22	10	15	22	10	17	22	10	18	22
290	6	10	13	6	11	13	7	11	16	8	11	17
300	4	5	8	4	5	7	4	7	8	4	8	9
310	1	2	3	1	2	3	1	2	3	1	2	3
Maximum	324	337	350	324	337	350	324	337	350	324	337	350

LAKE ST. LOUIS

380	8	14	6	9	14	6	11	15	7	12	16	7
390	5	14	6	5	14	6	5	14	5	6	14	5
400	5	13	3	5	13	3	5	14	3	5	14	3
410	3	9	2	3	9	2	4	12	2	4	10	3
420	2	5	1	2	5	1	2	5	1	2	6	1
430	1	3	1	1	3	1	1	3	1	1	3	1
440	1	2	0	1	2	0	1	2	0	1	2	0
450	1	0	0	1	0	0	1	0	0	1	0	0
Maximum	452	448	439	452	448	438	452	448	436	451	448	432

TABLE A-22

MINIMUM MONTHLY MEAN OUTFLOWS FROM LAKE ONTARIO
IN THOUSANDS OF CFS (1900-1976)

Month	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
January	185	185	185	185
February	182	182	182	182
March	179	179	179	179
April	177	177	177	177
May	176	176	176	176
June	190	190	190	189
July	200	200	199	198
August	201	201	200	199
September	201	200	200	199
October	196	196	196	195
November	198	198	198	198
December	192	192	192	192

Criterion (f): Consistent with other requirements, the maximum regulated outflow from Lake Ontario shall be maintained as low as possible to reduce channel excavation to a minimum.

The most important consideration in connection with Criterion (f) is that the plans should not produce more critical conditions than those under the current operating plan. Figure A-8 shows the open-water envelope of water levels versus flows for Plan 1958-D and the selected plans. Consideration of the points outside the envelope of Plan 1958-D indicates that conditions under the plans provide for higher flow at lower elevations. This would indicate that the velocity criterion for the river has not been satisfied to the same degree as under the basis-of-comparison. However, it should be noted that there was no attempt to do so under Category 1.

Criterion (g): Consistent with other requirements, the levels of Lake Ontario shall be regulated for the benefit of property owners on the shores of Lake Ontario in the United States and Canada so as to reduce the extremes of levels which have been experienced.

TABLE A-23
COMPARISON OF LAKE ONTARIO LEVELS

	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
Mean	244.61	244.64	244.65	244.63
Maximum	247.37	247.39	247.56	247.50
Minimum	241.81	241.74	241.59	241.38
Range	5.56	5.65	5.97	6.12

Table A-23 shows a comparison of the lake level conditions resulting under the three plans with those of the basis-of-comparison. The table shows that as the inflow capacity increases, as indicated by the plan, the range of extreme levels also increases. In general the criterion has not been satisfied to the same degree as the basis-of-comparison. However, it should be noted that there was no attempt to do so under Category 1 studies. Modification to Plan 1958-D to accommodate the increased flow was accomplished and is discussed under Categories 2 and 3.

Criterion (h): The regulated monthly mean level of Lake Ontario shall not exceed elevation 246.77 with the supplies of the past as adjusted.

Table A-24 is consistent with the finding under Criterion (g). As the outflow from Lake Erie is increased the exceedence of 246.77 is increased. However, as stated under Criterion (g) there has been no attempt under Category 1 plans to offset this increase.

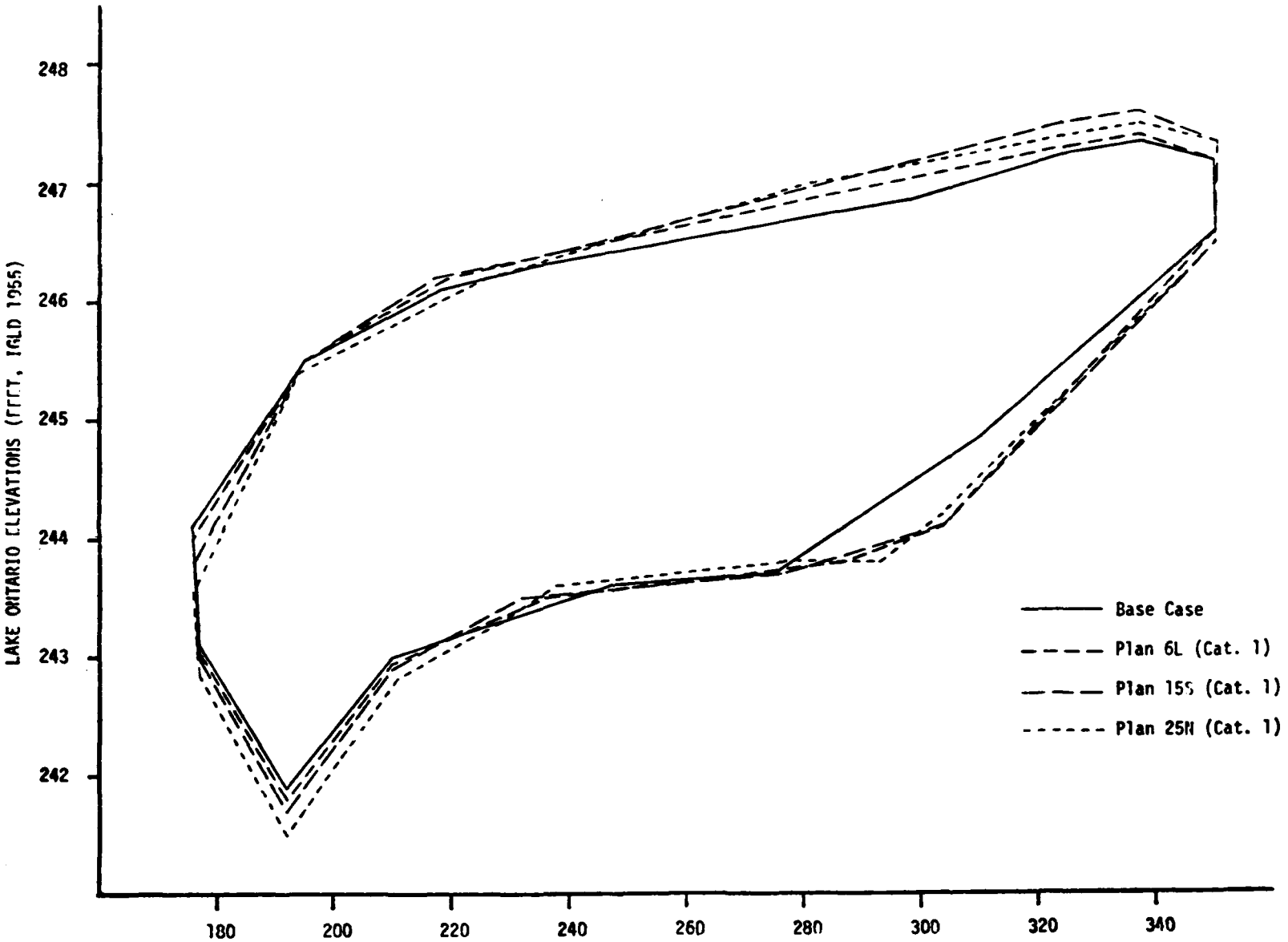


Figure A-8

Envelope of Lake Ontario Water Levels vs. Outflow - Category 1

TABLE A-24

MONTHLY MEAN LEVELS OF LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE ELEVATION 246.77)

PLAN	OCCURRENCES
Basis-of-Comparison	8
Plan 6L	9
Plan 15S	10
Plan 25N	14

TABLE A-25

MONTHLY MEAN LEVELS OF LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES EQUAL TO OR ABOVE ELEVATION 245.77)

PLAN	OCCURRENCES
Basis-of-Comparison	100
Plan 6L	103
Plan 15S	112
Plan 25N	114

Criterion (i): Under regulation, the frequency of occurrences of monthly mean elevations of approximately 245.77 and higher on Lake Ontario shall be less than would have occured in the past with the supplies of the past as adjusted and with present channel conditions in the Galop Rapids reach of the International Rapids Section of the St. Lawrence River.

Table A-25 reflects the same condition enumerated under Criteria (g) and (h).

Criterion (j): The regulated level of Lake Ontario on 1 April shall not be lower than elevation 242.77. The regulated mean level of the lake from 1 April to 30 November shall be maintained at or above elevation 242.77.

Table A-26 shows a general lowering of the 1 April level and of the minimum monthly mean level for the period April thru November under all three plans, as compared to those which occurred under the basis-of-comparison. Hence, the criterion has not been satisfied to the same degree. (See note Criterion (g)).

Criterion (k): In the event that future supplies occur in excess of the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to the riparian owners upstream and downstream. In the event of future supplies less than the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to navigation and power interests.

All plans were developed using the supplies of the past as adjusted, and this criterion refers to magnitudes and sequences of supplies in the future that may be more critical than those of the past. Since this condition refers to future conditions, it cannot be evaluated.

Lake St. Louis Low Water Levels: One supplementary requirement of regulation relates to Lake St. Louis low water levels and states that "The project works shall be operated in such a manner as to provide no less protection for navigation and riparian interests downstream than would have occurred under preproject conditions with the supplies of the past as adjusted, as defined in Criterion (a) herein."

Table A-27 shows that the minimum level under all three plans has been lowered slightly below that which occurred under the basis-of-comparison. The frequency of the occurrence of these low levels under Plans 15S and 25N has also been increased when compared to those of the basis-of-comparison. However, as noted above no attempt has been made to adjust for this condition.

TABLE A-26

LAKE ONTARIO WATER LEVELS
MINIMUM 1 APRIL - MINIMUM APRIL-NOVEMBER

PLAN	MINIMUM 1 APRIL	MINIMUM MONTHLY MEAN APR-NOV
Basis-of-Comparison	242.62	242.25
Plan 6L	242.56	242.19
Plan 15S	242.46	242.04
Plan 25N	242.24	241.89

TABLE A-27

LAKE ST. LOUIS LOW WATER LEVELS
JUNE, JULY, AUGUST, SEPTEMBER
1900-1976

(NUMBER OF MONTHS BELOW VALUES SHOWN)

Stage	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
67.0	77	77	86	87
66.5	36	36	38	39
66.0	8	7	7	7
65.5	0	0	0	2
65.0	0	0	0	0
Minimum	65.55	65.53	65.53	65.48

4.3 Category 2 and 3 Plans

As noted previously, Categories 2 and 3 consist of modification to the Lake Ontario portion of the Category 1 plans to accommodate Lake Erie regulation. Category 2 consists of modifying Plan 1958-D to such an extent as to satisfy the previously stated Lake Ontario criteria to the same degree as occurred under actual operation. Category 3 consists of modifying Plan 1958-D and enlarging the St. Lawrence River channels to such an extent as to satisfy the criteria as stated and accommodate Lake Erie regulation. As part of this latter exercise the basis-of-comparison has also been modified to satisfy these criteria and is shown on the following tables as the adjusted basis-of-comparison. Rather than restate the criteria (given above) in their entirety, they have been paraphrased in the following section.

Criterion (a): Mean outflows from Lake St. Louis.

Table A-28 shows the results obtained under Categories 2 and 3 modifications to Regulation Plan 1958-D. The table shows that the minimum flows from Lake St. Louis under Plans 6L and 15S, for both Categories 2 and 3, are equal to or greater than those which occurred under the basis-of-comparison and the adjusted basis-of-comparison. However, Plan 25N produces slightly lower minimum flows. The table further shows that under both of these categories there is an increase in the frequency of occurrence of flows below 230,000 cfs under Plans 15S and 25N. Below 225,000 cfs this condition is reduced and the values departed only slightly from the adjusted basis-of-comparison.

Criterion (b): Winter outflows from Lake Ontario.

Table A-29 shows that regulation of Lake Erie would provide an improvement in the minimum flow situation on Lake Ontario in both categories, when compared to the basis-of-comparison. A comparison of Category 2 maximum flow conditions indicates a general reduction in high flows. This is also true in the comparison of the adjusted basis-of-comparison with the basis-of-comparison. Under Category 3 the three plans produce results (maximums, minimums and averages) similar to those obtained under the adjusted basis-of-comparison.

Criterion (c): Outflow from Lake Ontario during spring breakup in Montreal Harbour.

Table A-30 shows a general reduction in the maximum flow during March, when compared to the basis-of-comparison. However, the table also shows a general increase in the frequency of high flows (above 250,000 cfs) under Categories 2 and 3 when compared to the basis-of-comparison and/or the adjusted basis-of-comparison.

During April, under Category 2 Plans 15S and 25N, there is both an increase in the maximum and the frequency of occurrence of high flows in

TABLE A-28

MONTHLY MEAN OUTFLOWS FROM LAKE ST. LOUIS
APRIL 1 - DECEMBER 15 (1900 - 1976)
NUMBER OF OCCURRENCES BELOW OUTFLOW SHOWN

CATEGORY 2

Outflow (Thousands of CFS)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
230	27-1/2	29-1/2	31	35-1/2
225	15	14	15-1/2	17-1/2
220	9-1/2	6	6	11-1/2
215	5	2	2	2
210	0	0	0	0
205	0	0	0	0
200	0	0	0	0
195	0	0	0	0
Minimum	212	213	212	211

CATEGORY 3

Outflow (Thousands of CFS)	Basis-of-Comparison	Adjusted Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
230	27-1/2	30	30	31-1/2	37-1/2
225	15	15-1/2	15-1/2	16-1/2	18
220	9-1/2	8-1/2	8-1/2	11-1/2	11-1/2
215	5	2	2	2	2
210	0	0	0	0	0
205	0	0	0	0	0
200	0	0	0	0	0
195	0	0	0	0	0
Minimum	212	212	212	212	211

TABLE A-29

WINTER OUTFLOWS FROM LAKE ONTARIO (1900-1976)
(IN THOUSANDS OF CUBIC FEET PER SECOND)

CATEGORY 2

	Basis-of-Comparison			Plan 6L			Plan 15S			Plan 25N		
PERIOD	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.
Dec. 15-31	279	188	226	296	205	231	296	204	231	296	202	230
January	250	185	217	235	205	218	235	204	216	235	202	217
February	285	182	228	280	202	229	280	200	229	280	200	229
March	300	179	234	297	195	233	297	196	234	297	195	232

CATEGORY 3

	Basis-of-Comparison			Adjusted Basis-of-Comparison			Plan 6L			Plan 15S			Plan 25N		
PERIOD	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.
Dec. 15-31	279	188	226	304	203	229	304	203	229	309	202	230	304	200	228
January	250	185	217	234	203	214	234	203	215	234	202	215	235	200	213
February	285	182	228	280	200	230	280	200	230	280	200	231	280	200	230
March	300	179	234	294	196	233	295	196	234	296	195	235	295	195	233

TABLE A-30

MEAN MARCH OUTFLOWS FROM LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)
CATEGORY 2

Outflow (Thousands of CFS)	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
250	19	20	22	23
260	11	8	11	11
270	7	7	7	8
280	4	4	4	3
290	2	1	2	1
Maximum	300	297	297	297

MEAN FIRST HALF APRIL OUTFLOWS FROM LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

250	28	28	30	29
260	17	15	20	21
270	11	11	13	14
280	6	8	9	9
290	5	6	6	6
Maximum	318	318	320	319

CATEGORY 3
MEAN MARCH OUTFLOWS FROM LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

Outflow (Thousands of CFS)	Basis-of-Comparison	Adjusted Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
250	19	23	23	26	25
260	11	11	13	15	16
270	7	7	7	8	8
280	4	4	4	6	4
290	2	1	1	1	1
Maximum	300	294	295	297	295

TABLE A-30 (Cont'd)

CATEGORY 3

MEAN FIRST HALF APRIL OUTFLOW FROM LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

Outflow (Thousands of CFS)	Basis-of-Comparison	Adjusted Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
250	28	29	30	33	30
260	17	19	20	23	25
270	11	12	13	16	15
280	6	10	11	12	12
290	5	9	9	9	9
Maximum	318	331	332	336	332

comparison to the basis-of-comparison. This is also true of Category 3, when comparing the plans with the adjusted basis-of-comparison. In general, the three Lake Erie regulation plans being evaluated do not satisfy this criterion as well as the present conditions do.

Criterion (d): Annual flood discharge Ottawa River.

The annual flood discharge is evaluated by comparison of flows out of Lake Ontario and Lake St. Louis, during the months of April, May, and June. Table A-31 provides this comparison. The table shows that under Category 2 the maximum outflows are less then, but the frequency of high flows from Lake Ontario under the plans are approximately the same as under the basis-of-comparison. However, for Lake St. Louis outflow, even though the maximum flow is somewhat higher, the frequency of flows above 380,000 cfs is approximately the same as occurred under the basis-of-comparison. Category 3, in comparison to the adjusted basis-of-comparison, shows an increase in the maximum flow from Lake Ontario under Plan 15S. However, there is very little impact on Lake St. Louis. The same conditions prevail under the frequency comparison, i.e, a slight increase in high flow from Lake Ontario with little impact on Lake St. Louis, when compared with the adjusted basis-of-comparison. It should be noted that under Category 3 there would be channel improvements in both the International and Canadian reaches of the river. These improvements should offset the effect of these high flows and make the level conditions no worse than occurred under the basis-of-comparison.

Criterion (e): Minimum outflow from Lake Ontario.

Table A-32 compares the minimum flows resulting under each regulation plan for both Categories 2 and 3. The table shows that both categories provide higher minimum flows than under the basis-of-comparison. These flows are approximately the same as occurred under the adjusted basis-of-comparison, except under Plan 25N.

Criterion (f): Maintain the maximum outflows as low as possible so as to reduce Channel excavation.

The most important consideration in connection with Criterion (f) is that the plans should not produce more critical conditions than those which occur under the current operating plan. It should be noted that the current operating rule does not satisfy the criteria over the 1900-1976 study period. Hence, to evaluate this criterion and to determine that portion of the channel increase which can be attributed to Lake Erie regulation, it was first necessary to adjust the basis-of-comparison so that it satisfied the criteria (called the adjusted basis-of-comparison in this report). Figure A-9 shows the open-water envelope of water levels versus outflows for the Category 2 Plans. Neither these plans nor the basis-of-comparison satisfy the requirement. Figure A-10 shows that if the necessary channel modifications were made, as required by the adjusted basis-of-comparison to satisfy the requirement, these modifications would be adequate to handle Plan 6L. Plans 15S and 25N, however, would require further minor channel enlargements.

TABLE A-31
MONTHLY MEAN OUTFLOWS FROM LAKE ONTARIO AND LAKE ST. LOUIS
APRIL, MAY AND JUNE (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

CATEGORY 2

LAKE ONTARIO

Outflow (Thousands of CFS	Basis-of-Comparison			Plan 6L			Plan 15S			Plan 25N		
	April	May	June	April	May	June	April	May	June	April	May	June
260	22	31	30	22	31	30	28	31	30	26	30	32
270	12	24	27	13	24	27	17	26	27	16	26	27
280	9	15	22	11	15	21	10	17	21	11	19	22
290	6	10	13	6	11	13	8	12	15	9	11	17
300	4	5	8	4	6	9	5	7	9	5	8	9
310	1	2	3	2	3	4	3	3	4	1	3	6
Maximum	324	337	350	321	324	325	322	325	326	322	325	326
LAKE ST. LOUIS												
380	8	14	6	10	14	6	12	18	7	11	18	8
390	5	14	6	5	14	4	5	14	3	6	14	3
400	5	13	3	5	11	3	5	13	3	5	13	3
410	3	9	2	3	8	1	4	9	1	4	9	2
420	2	5	1	2	5	1	2	5	1	2	5	1
430	1	3	1	1	3	1	1	3	1	1	3	1
440	1	2	0	1	2	0	1	2	0	1	1	0
450	1	0	0	1	1	0	1	1	0	1	1	0
Maximum	452	448	439	459	458	438	458	460	436	454	459	432

TABLE A-31 (Cont'd)

MONTHLY MEAN OUTFLOWS FROM LAKE ONTARIO AND LAKE ST. LOUIS
APRIL, MAY AND JUNE (1900-1976)
(NUMBER OF OCCURRENCES ABOVE OUTFLOW SHOWN)

CATEGORY 3

LAKE ONTARIO

Outflow (Thousands of CFS	Basis-of-Comparison			Adjusted Basis-of-Comparison			Plan 6L			Plan 15S			Plan 25N		
	April	May	June	April	May	June	April	May	June	April	May	June	April	May	June
260	22	31	30	23	31	30	23	31	30	29	31	30	25	29	32
270	12	24	27	15	24	27	15	23	26	18	26	26	15	26	25
280	9	15	22	12	17	23	11	16	20	13	18	21	12	20	21
290	6	10	13	9	13	14	9	12	14	10	12	15	9	14	18
300	4	5	8	6	7	9	7	7	8	9	7	11	8	8	12
310	1	2	3	4	4	6	4	4	6	5	6	6	5	6	6
Maximum	324	337	350	332	334	334	333	334	334	338	340	337	333	334	334

LAKE ST. LOUIS

380	8	14	6	10	15	10	11	15	9	12	18	10	12	18	10
390	5	14	6	6	14	5	9	14	5	10	14	4	11	14	6
400	5	13	3	5	13	3	5	13	3	5	13	3	5	13	4
410	3	9	2	5	9	3	5	9	3	5	10	3	5	10	3
420	2	5	1	4	7	1	4	6	1	5	6	1	4	7	2
430	1	3	1	2	5	1	2	5	1	2	6	1	2	6	1
440	1	2	0	1	3	1	1	3	1	2	3	1	2	2	1
450	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
Maximum	452	448	439	473	468	453	473	468	452	473	473	451	469	469	446

TABLE A-32

MINIMUM MONTHLY MEAN OUTFLOWS FROM LAKE ONTARIO
IN THOUSANDS OF CFS (1900-1976)

CATEGORY 2

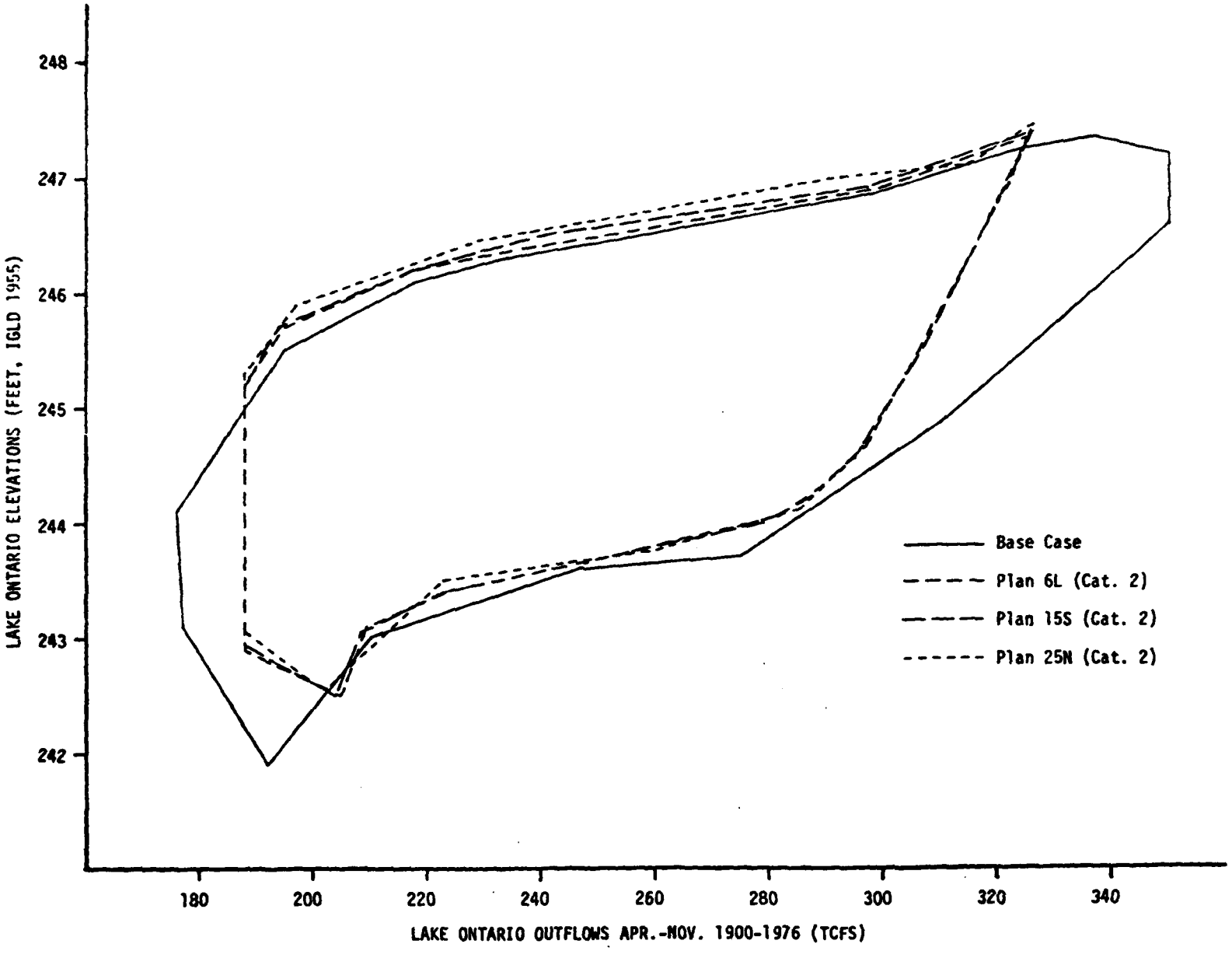
Month	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
January	185	205	204	202
February	182	202	200	200
March	179	195	196	195
April	177	188	188	188
May	176	188	188	188
June	190	194	193	192
July	200	200	199	198
August	201	201	200	199
September	201	202	202	202
October	196	205	204	202
November	198	205	204	202
December	192	205	204	202

TABLE A-32 (Cont'd)

MINIMUM MONTHLY MEAN OUTFLOWS FROM LAKE ONTARIO
IN THOUSANDS OF CFS (1900-1976)

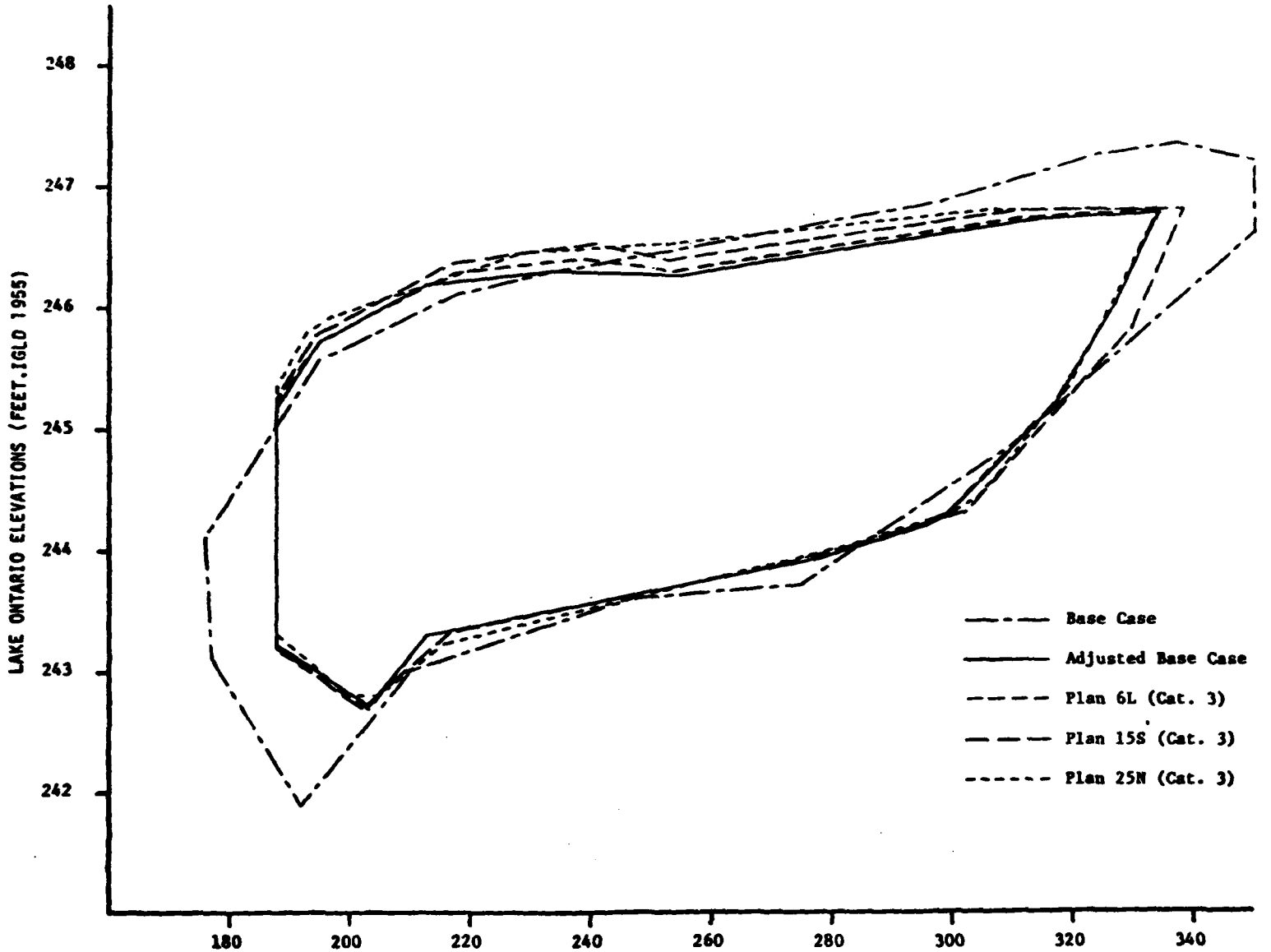
CATEGORY 3

Month	Basis-of-Comparison	Adjusted Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
January	185	203	203	202	200
February	182	200	200	200	200
March	179	196	196	195	195
April	177	188	188	188	188
May	176	188	188	188	188
June	190	193	193	193	192
July	200	200	200	199	198
August	201	201	201	200	199
September	201	202	202	202	200
October	196	203	203	202	200
November	198	203	203	202	200
December	192	203	203	202	200



Envelope of Lake Ontario Water Levels vs. Outflow - Category 2

Figure A-9



Envelope of Lake Ontario Water Levels vs. Outflow - Category 3

Figure A-10

Criterion (g): Monthly mean Lake Ontario levels.

Table A-33 shows a comparison of the maximum, mean and minimum levels under all plans in comparison to those which occurred under the basis-of-comparison and the adjusted basis-of-comparison. The table shows that the maximum stage criterion would have been approximately satisfied under both Categories 2 and 3 in comparison to that which occurred under the appropriate basis-of-comparison. Under both categories the minimum level has been raised. Hence, under both categories all plans satisfy the criterion to a higher degree than the basis-of-comparison.

Criterion (h): Monthly occurrence above 246.77.

In comparing Category 2 Plans, to the basis-of-comparison and Category 3 plans to the adjusted basis-of-comparison, an increase in the number of occurrences above 246.77 is seen (Table A-34). However, since these increases are less than 0.1 foot (Table A-33) it was concluded that this criterion has been satisfied.

Criterion (i): Monthly occurrence above 245.77.

Table A-35 compares the frequency of occurrence of levels above 245.77. The table shows that the Category 2 plans do not satisfy the criterion to the same degree as under the current operating rule nor do the Category 3 plans, when compared to the adjusted basis-of-comparison. However, under Category 3 the plans show a reduction in the frequency of occurrence of these high levels and, hence, has satisfied this criterion to a higher degree than the current operating rule, but not to the same degree as the adjusted basis-of-comparison.

Criterion (j): Minimum level during the navigation season.

Table A-36 shows that under both Categories 2 and 3 the minimum monthly mean level during the period April thru November is higher than that stipulated by the criterion (242.77 feet); hence, this portion of the criterion has been satisfied by all plans. Under all Category 2 plans the 1 April level stipulated by the criterion has not been attained, and, hence, the criterion as a whole has not been satisfied. All Category 3 plans satisfy the 1 April criterion, as does the adjusted basis-of-comparison.

Criterion (k): See discussion under Category 1.

Lake St. Louis: Supplementary requirement related to low levels.

Table A-37 shows that the minimum level which would have resulted under the three plans are approximately the same as those which would have occurred under the basis-of-comparison and/or the adjusted basis-of-comparison. The table also shows that the frequency of occurrence below 66.5 ft. is

TABLE A-33

MONTHLY MEAN LEVELS OF LAKE ONTARIO (1900-1976)

CATEGORY 2

Water Levels	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
Mean	244.61	244.66	244.69	244.71
Maximum	247.37	247.34	247.42	247.45
Minimum	241.81	242.04	242.12	242.21
Range	5.56	5.30	5.30	5.24

CATEGORY 3

Water Levels	Basis-of-Comparison	Adjusted Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
Mean	244.61	244.63	244.64	244.65	244.67
Maximum	247.37	246.77	246.79	246.84	246.83
Minimum	241.81	242.38	242.32	242.34	242.47
Range	5.56	4.39	4.47	4.50	4.36

TABLE A-34

MONTHLY MEAN LEVELS OF LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES ABOVE ELEVATION 246.77)

CATEGORY 2

PLAN	OCCURRENCES
Basis-of-Comparison	8
Plan 6L	11
Plan 15S	13
Plan 25N	17

CATEGORY 3

PLAN	OCCURRENCES
Basis-of-Comparison	8
Adjusted Basis-of-Comparison	0
Plan 6L	1
Plan 15S	3
Plan 25N	4

TABLE A-35

MONTHLY MEAN LEVELS OF LAKE ONTARIO (1900-1976)
(NUMBER OF OCCURRENCES EQUAL TO OR ABOVE ELEVATION 245.77)

CATEGORY 2

PLAN	OCCURRENCES
Basis-of-Comparison	100
Plan 6L	104
Plan 15S	110
Plan 25N	121

CATEGORY 3

PLAN	OCCURRENCES
Basis-of-Comparison	100
Adjusted Basis-of-Comparison	86
Plan 6L	88
Plan 15S	90
Plan 25N	92

TABLE A-36

LAKE ONTARIO WATER LEVELS
MINIMUM 1 APRIL & MINIMUM APRIL - NOVEMBER

CATEGORY 2

PLAN	MINIMUM 1 APRIL	MINIMUM MONTHLY MEAN APR - NOV
Basis-of-Comparison	242.62	242.25
Plan 6L	242.48	242.89
Plan 15S	242.56	242.97
Plan 25N	242.63	243.04

CATEGORY 3

PLAN	MINIMUM 1 APRIL	MINIMUM MONTHLY MEAN APR - NOV
Basis-of-Comparison	242.62	242.25
Adjusted Basis-of-Comparison	242.82	243.22
Plan 6L	242.76	243.16
Plan 15S	242.80	243.19
Plan 25N	242.67	243.24

TABLE A-37

LAKE ST. LOUIS LOW WATER LEVELS*
JUNE, JULY, AUGUST, SEPTEMBER
1900-1976
(NUMBER OF MONTHS BELOW LEVEL SHOWN)

CATEGORY 2

Stage	Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
67.0	77	73	81	85
66.5	36	36	37	39
66.0	8	6	7	8
65.5	0	0	0	1
65.0	0	0	0	0
Minimum	65.55	65.56	65.53	65.48

CATEGORY 3

Stage	Basis-of-Comparison	Adjusted Basis-of-Comparison	Plan 6L	Plan 15S	Plan 25N
67.0	77	74	74	82	85
66.5	36	36	37	37	32
66.0	8	8	7	7	8
65.5	0	0	0	0	1
65.0	0	0	0	0	0
Minimum	65.55	65.55	65.55	65.53	65.48

*AT LOCK 5, LACHINE

approximately the same. Hence, under all comparisons this requirement is satisfied to approximately the same degree.

Criteria (a), (c), and (d) relate to outflows from Lakes Ontario and St. Louis. To measure the full impact over the entire test period and range of flows Figures A-11 and A-12 have been prepared for Category 2 and Figures A-13 and A-14 for Category 3. Figure A-11 shows that the frequency of occurrence of flow between 230,000 and 194,000 cfs, under the regulation plans, is less than that of the basis-of-comparison. The reverse is true for values above 230,000 cfs, where the regulation plans provide for greater flows. Figure A-12 reflects the same pattern, i.e., increased frequency of flows under regulation above 280,000 cfs, reduced frequency between 280,000 and 210,000 cfs, and increased flow below that point.

Figure A-13, which evaluates Category 3, shows that the frequency of occurrence of outflows from Lake Ontario under the adjusted basis-of-comparison increases over the basis-of-comparison employed for Category 2, for values above 230,000 cfs. The adjusted basis-of-comparison is less than the basis-of-comparison between values of 230,000 and 195,000 cfs and above for values below that level. In comparing the adjusted basis-of-comparison with the regulation plans, only Plan 25N shows a marked deviation: having flows greater than the adjusted basis-of-comparison in the range above 255,000 cfs, and lower flows in the range below 230,000 cfs. Figure A-14 shows the same general pattern for Lake St. Louis outflows. On this figure the deviations from the adjusted basis-of-comparison are less pronounced.

4.4 Summary

The regulation plans were developed employing the hydrologic data for the period 1900-1976, with the intent of reducing the high levels of the Great Lakes as required by the Reference from the Governments. Table A-38 summarizes the information presented in the previous section for all three categories. On the table, the following legend has been employed:

1. indicates that the criterion has been satisfied;

2. indicates that the criterion has been satisfied and there was improvement over the basis-of-comparison;

3. indicates that the criterion has not been satisfied; and

4. indicates that the criterion has not been satisfied, but there was improvement upon the basis-of-comparison.

The table shows that on Lakes Superior, Michigan-Huron and Erie those criteria related to high lake levels have been satisfied and the frequency

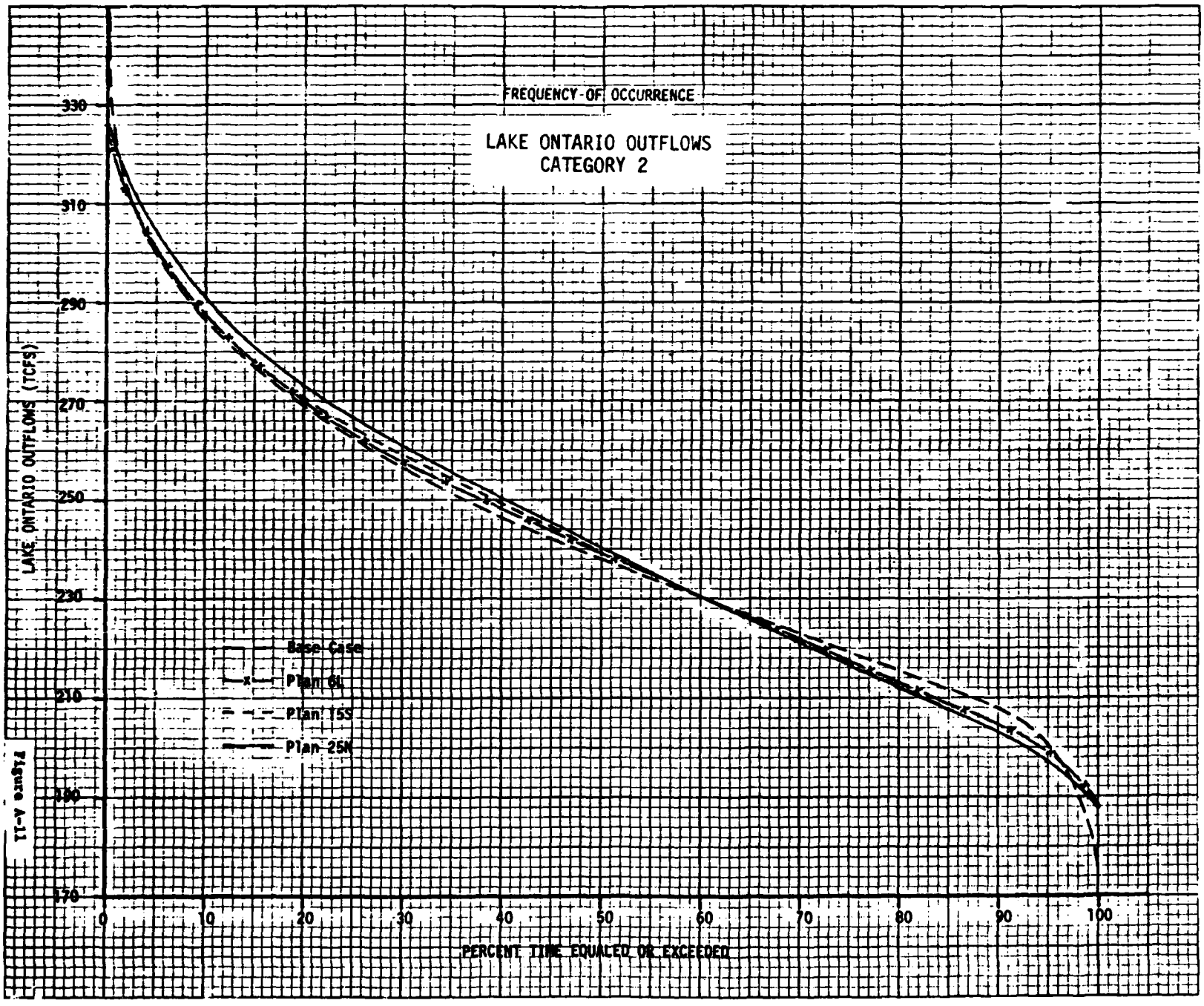

FREQUENCY-OF OCCURRENCE
LAKE ONTARIO OUTFLOWS
CATEGORY 2
LAKE ONTARIO OUTFLOWS (TCFS)
330
310
290
270
250
230
210
190
170
Base Case
Plan 6L
Plan 15S
Plan 25K
0
10
20
30
40
50
60
70
80
90
100
PERCENT TIME EQUALED OR EXCEEDED

Figure A-11

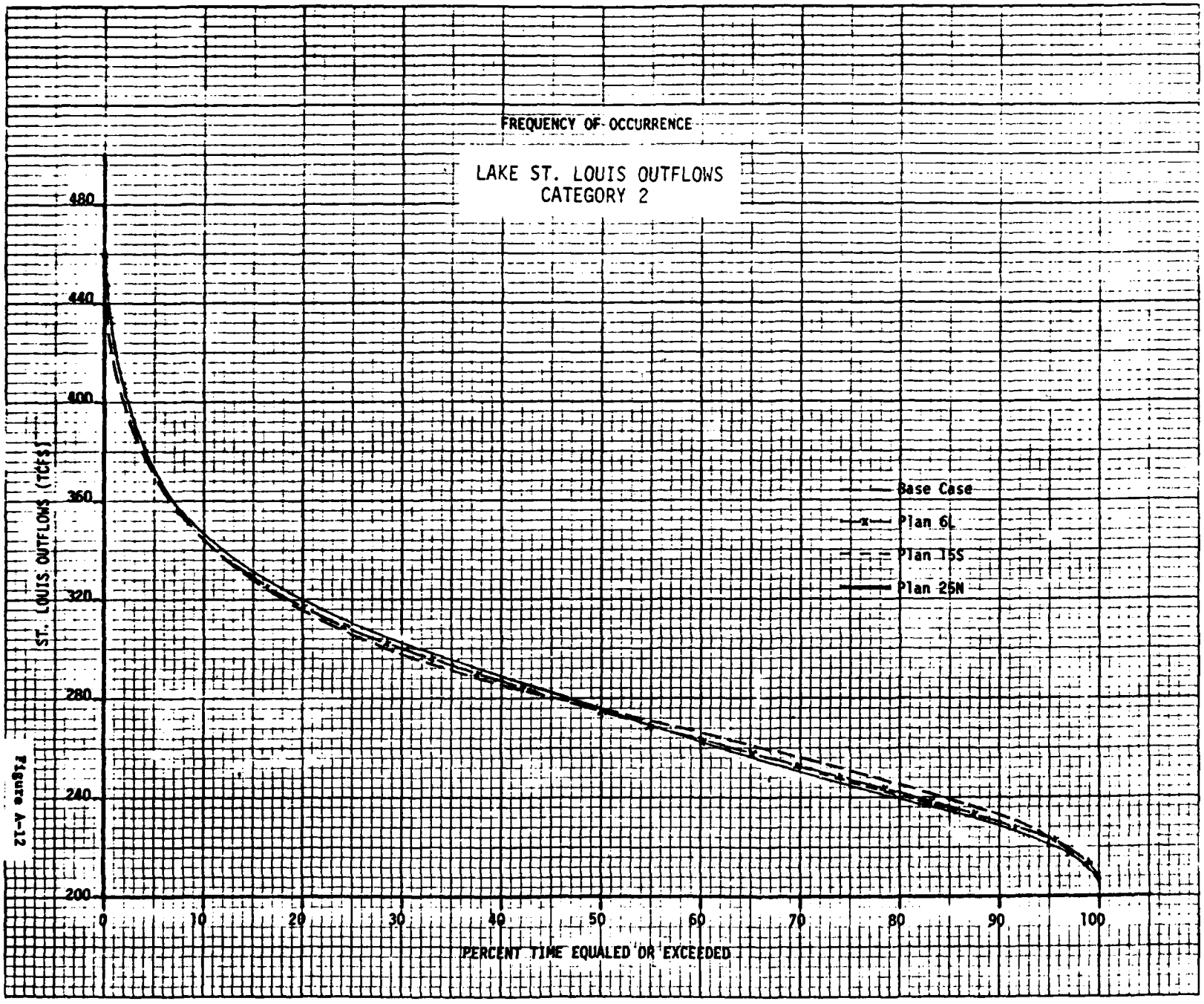

FREQUENCY OF OCCURRENCE
LAKE ST. LOUIS OUTFLOWS
CATEGORY 2
ST. LOUIS OUTFLOWS (TCFS)
480
440
400
360
320
280
240
200
0
10
20
30
40
50
60
70
80
90
100
PERCENT TIME EQUALED OR EXCEEDED
Base Case
Plan 6L
Plan 15S
Plan 25N

Figure A-12

AD-A114 583 INTERNATIONAL LAKE ERIE REGULATION STUDY BOARD F/G 13/2
LAKE ERIE WATER LEVEL STUDY. APPENDIX A. REGULATION. VOLUME I.(U)
JUL 81

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2 2

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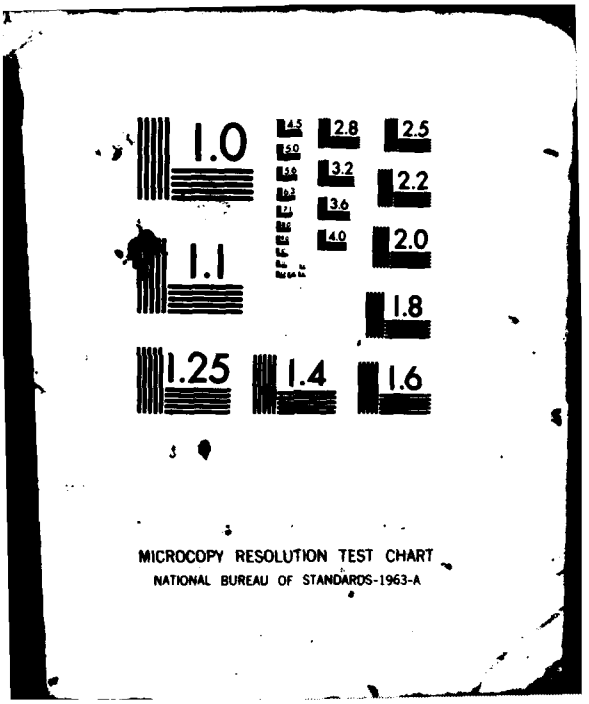
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1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

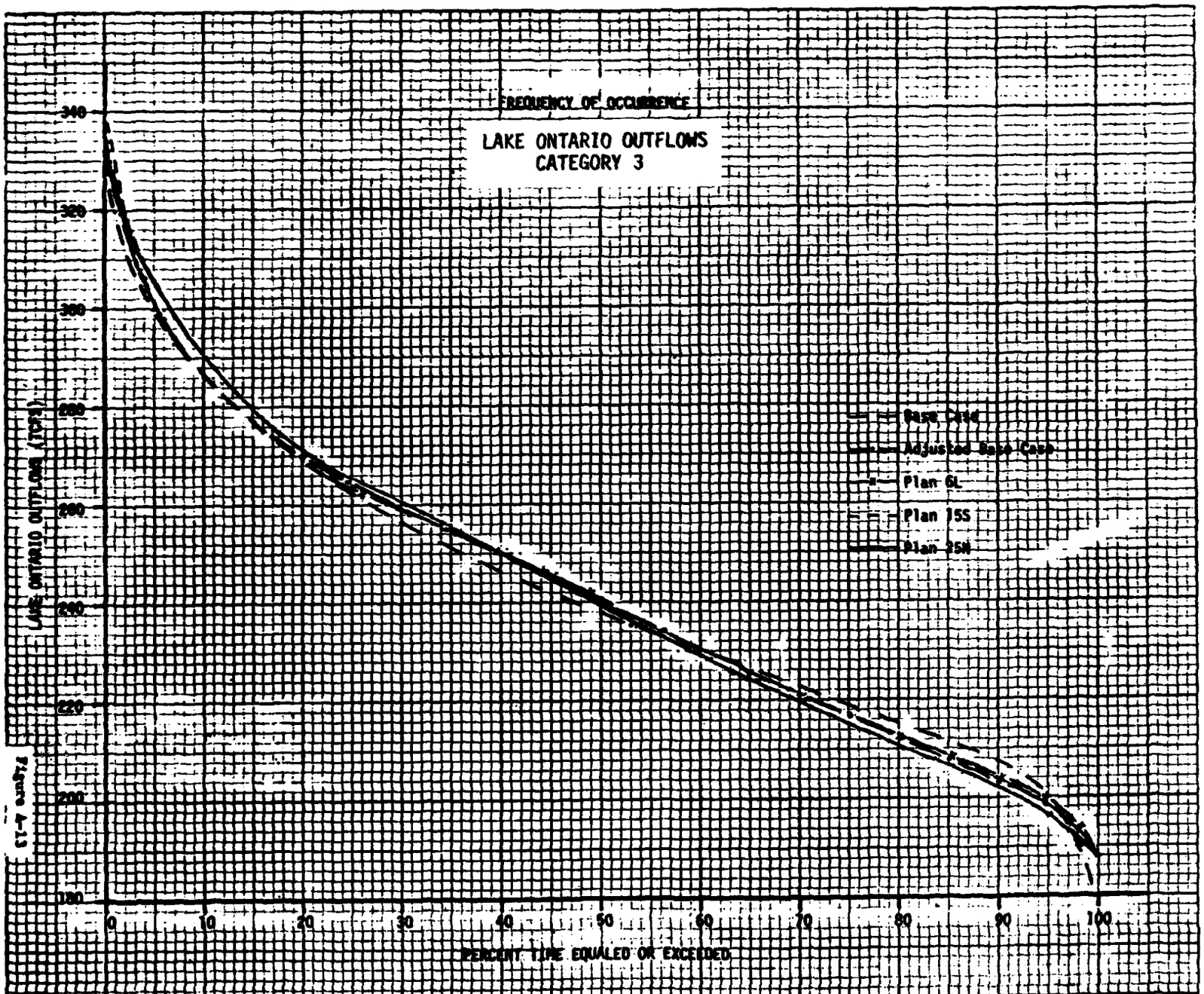

FREQUENCY OF OCCURRENCE
LAKE ONTARIO OUTFLOWS
CATEGORY 3
LAKE ONTARIO OUTFLOWS (TCFS)
340
320
300
280
260
240
220
200
180
0
10
20
30
40
50
60
70
80
90
100
PERCENT TIME EQUALED OR EXCEEDED
Base Case
Adjusted Base Case
Plan 6L
Plan 15S
Plan 25N

Figure 4-13

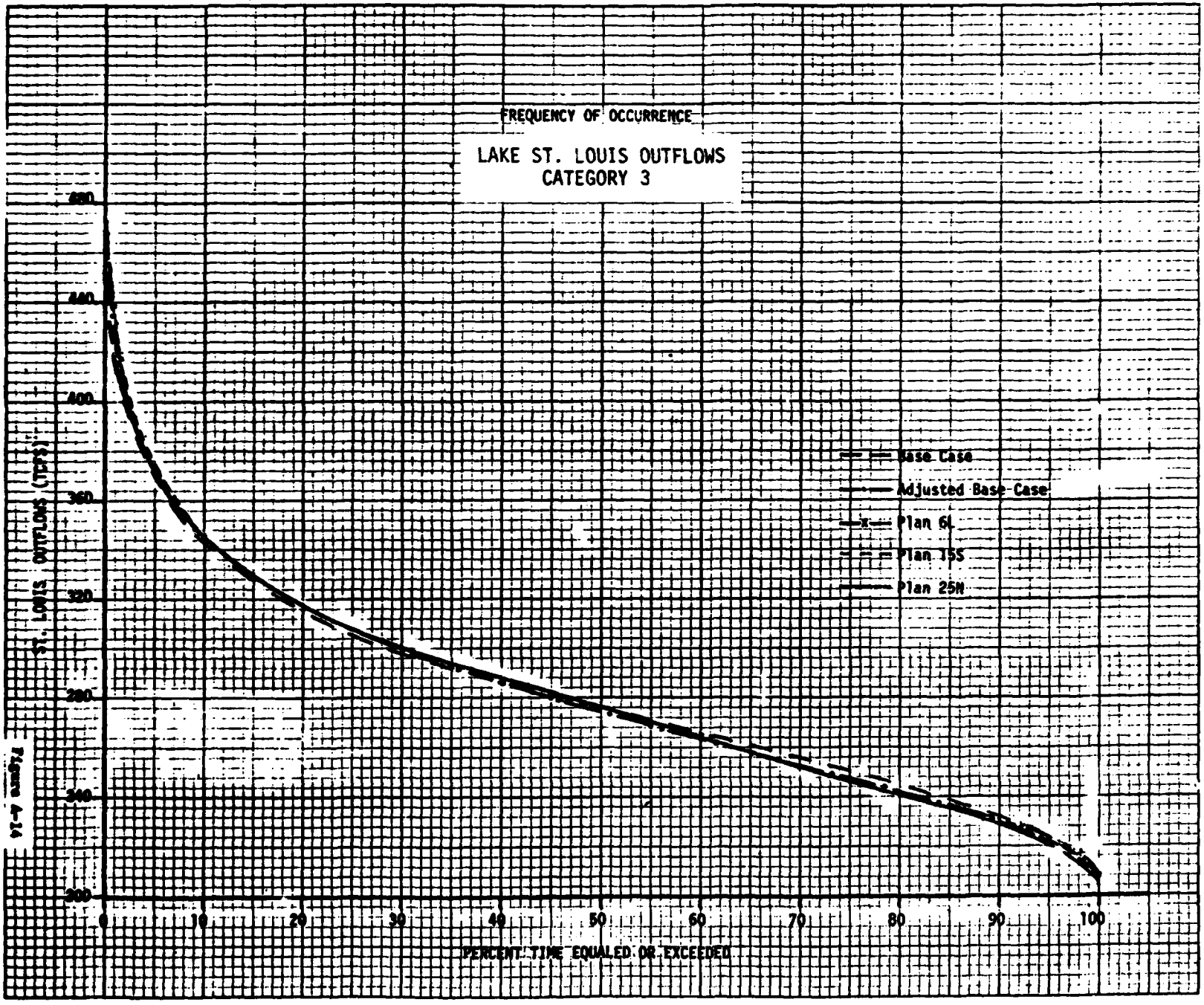

FREQUENCY OF OCCURRENCE
LAKE ST. LOUIS OUTFLOWS
CATEGORY 3
ST. LOUIS OUTFLOWS (TDFS)
480
440
400
360
320
280
240
200
0
10
20
30
40
50
60
70
80
90
100
PERCENT TIME EQUALED OR EXCEEDED
Base Case
Adjusted Base Case
Plan 6L
Plan 15S
Plan 25N

Figure 4-14

TABLE A-38
SUMMARY
PLANS VS. CRITERIA

	Plan 6L	Plan 15S	Plan 25N
Lake Superior			
Criterion (a)	3	3	3
Criterion (b)	2	2	2
Criterion (c)	1	1	1
Criterion (d)	1	1	2
Criterion (e)	1	2	2
Lakes Michigan-Huron			
Criterion (a)	2	2	2
Criterion (b)	3	3	3
Lake Erie			
Criterion (a)	2	2	2
Criterion (b)	3	3	3
Lake Ontario (Category 1)			
Criterion (a)	1	1	1
Criterion (b)	1	1	1
Criterion (c)	3	3	3
Criterion (d)	1	1	1
Criterion (e)	1	1	1
Criterion (f)	1	1	1
Criterion (g)	3	3	3
Criterion (h)	3	3	3
Criterion (i)	3	3	3
Criterion (j)	3	3	3
Criterion (k)	N/A	N/A	N/A
(supp)	1	3	3
Lake Ontario (Category 2)			
Criterion (a)	1	1	1
Criterion (b)	2	2	2
Criterion (c)	3	3	3
Criterion (d)	1	1	1
Criterion (e)	2	2	2
Criterion (f)	2	2	2
Criterion (g)	2	2	2
Criterion (h)	1	1	1
Criterion (i)	3	3	3

TABLE A-38 (Continued)
SUMMARY
PLANS VS. CRITERIA

	Plan 6L	Plan 15S	Plan 25N
Criterion (j) 1 April	3	3	4
Apr-Nov	2	2	2
Criterion (k)	N/A	N/A	N/A
(supp)	1	1	1
Lake Ontario (Category 3) vs. Adjusted Basis-of-Comparison			
Criterion (a)	1	3	3
Criterion (b)	1	1	1
Criterion (c)	1	1	1
Criterion (d)	1	1	1
Criterion (e)	1	1	1
Criterion (f)	1	1	1
Criterion (g)	1	3	3
Criterion (h)	1	1	1
Criterion (i)	3	3	3
Criterion (j) 1 April	1	1	3
Apr-Nov	1	1	2
Criterion (k)	N/A	N/A	N/A
(supp)	1	1	3

	Adjusted Basis-of-Comparison vs. Basis-of-Comparison
Criterion (a)	1
Criterion (b)	1
Criterion (c)	3
Criterion (d)	3
Criterion (e)	2
Criterion (f)	1
Criterion (g)	2
Criterion (h)	2
Criterion (i)	2
Criterion (j) 1 April	2
Apr-Nov	2
Criterion (k)	N/A
(supp)	2

of occurrence of those levels has been reduced. However, because of the depletion of storage by the increased discharge, the lowering of the high levels have also impacted on the lower levels. In general, on these lakes the summary shows that the intent of regulation under the Reference has been met.

On Lake Ontario, the summary shows that under Category 1, the discharging of additional water into that lake has a detrimental effect. However, the table also shows that when modifications to the regulation plan on that lake are instituted, as they are under Categories 2 and 3, this impact is offset and a general improvement over the appropriate basis-of-comparison is effected.

Section 5

EFFECT OF INTERNATIONAL GREAT LAKES DIVERSIONS AND CONSUMPTIVE USES STUDY BOARD RESULTS ON THE SELECTED PLANS

5.1 General

By letter dated February 21, 1977, the Governments of the United States and Canada requested the International Joint Commission to undertake the study reported on herein. By a second "Reference," of the same date, the Commission was requested by the Governments to "assess the effects of varying the rates of existing diversions during periods of extreme levels on the Great Lakes." Since diversions affect the water supply to the system, any modification thereof would impact on the regulation plans presented herein. To assess that impact, the diversion scenario developed by the International Diversion and Consumptive Uses Study Board having the greatest lowering effect on Great Lakes levels has been combined with selected regulation plans developed under this study. Those plans are Plan 6L, Plan 15S and Plan 25N. The impacts of diversion management on the selected plans are enumerated in the following paragraphs.

5.2 Diversion Management Scenario

The diversion management study assumed no changes in the present physical capacity of the diversion channels. The study further employed as a trigger, for changing the diversion rates, the water supply to Lakes Michigan-Huron. This trigger is comparable to the trigger employed for varying the outflow rates under the regulation plans presented herein. Diversions were varied as follows: from zero to 5,000 cfs in the case of the Long Lac-Ogoki Diversions; an increase from 3,200 cfs to annual average of 8,700 cfs out of Lake Michigan at Chicago and an increase from 7,000 cfs to 9,000 cfs through the Welland Canal. The maximum impact on lake levels occurs when the Long Lac-Ogoki diversions are reduced to zero; the Lake Michigan Diversion at Chicago is increased to 8,700 cfs; and the Welland Canal is increased to 9,000 cfs.

5.3 Hydrologic Evaluation of Diversion Management Scenarios on Selected Regulation Plans

Table A-39 shows the selected regulation plans with and without diversion management. The table shows that under all Category 3 plans on all lakes the maximum, minimum, and mean levels would be lower than those which occurred under the basis-of-comparison and the plans without diversion management. The table also shows that for all lakes (except Lake Ontario) the range of levels would be reduced. On Lake Ontario the table shows that there would be very

TABLE A-39

LAKE ERIE REGULATION
(LAKE ERIE REGULATION PLAN* COMBINED WITH DIVERSIONS AND CONSUMPTIVE USES STUDY BOARD SCENARIO**)

	Basis-of-Comparison	Plan 6L Without D.&C.U.	Plan 6L With D.&C.U.	Plan 15S Without D.&C.U.	Plan 15S With D.&C.U.	Plan 25N Without D.&C.U.	Plan 25N With D.&C.U.
Lake Superior							
Mean	600.44	600.43	600.29	600.41	600.27	600.37	600.22
Max	601.93	601.93	601.83	601.93	601.83	601.93	601.82
Min	598.69	598.68	598.57	598.65	598.58	598.62	598.52
Range	3.24	3.25	3.26	3.28	3.25	3.31	3.30
Lakes Michigan-Huron							
Mean	578.27	578.24	577.88	578.18	577.83	578.05	577.70
Max	581.15	581.09	580.51	580.99	580.40	580.75	580.21
Min	575.47	575.45	575.28	575.42	575.25	575.36	575.19
Range	5.68	5.64	5.23	5.57	5.15	5.39	5.02
Lake Erie							
Mean	570.76	570.67	570.39	570.53	570.25	570.17	569.88
Max	573.60	573.45	572.99	573.18	572.71	572.53	572.06
Min	568.09	568.07	567.93	568.02	567.89	567.84	567.71
Range	5.51	5.38	5.06	5.16	4.82	4.69	4.35
Lake Ontario (With Deviation)							
Mean	244.61	244.64	244.60	244.65	244.59	244.67	244.60
Max	247.37	246.79	246.78	246.84	246.83	246.83	246.82
Min	241.81	242.32	241.84	242.34	241.69	242.47	241.82
Range	5.56	4.47	4.94	4.50	5.14	4.36	5.00

*CATEGORY 3 - WITH LIMITATIONS ADJUSTED AS REQUIRED FOR LAKE ERIE REGULATION STUDY (NOT OPTIMIZED)
**LONG LAC/OGOKI DIVERSIONS 0; LAKE MICHIGAN DIVERSION AT CHICAGO AT 8,700 CFS AND WELLAND CANAL AT 9,000 CFS

little change in the maximum or mean stages; however, the minimum stage* would be reduced to that which would have occurred under the basis-of-comparison. As a result, there would also be an expansion of the range of levels. However, this increase in range is still less than that which occurred under the basis-of-comparison.

*It should be noted that no attempt was made to modify the Category 3 Lake Ontario plans to offset the effect of the reduced water supply. If the type of diversion management contemplated in the Diversion and Consumptive Uses Study were implemented, such an adjustment would be necessary to offset the effect of the reduced water supply.

Section 6

SUMMARY

6.1 Summary

Lakes Superior and Ontario are currently regulated using regulation plans known as Plan 1977 and Plan 1958-D, respectively. These regulation plans were developed to satisfy criteria specified by the International Joint Commission. The regulatory works employed in these plans are located in the St. Marys and St. Lawrence Rivers, and are so constructed to have full control of the outflow from Lakes Superior and Ontario. As a result, outflows may be increased or decreased to reduce or support the high and low levels of the lake. This is in contrast to what has been proposed for the regulation of Lake Erie. The works have been so conceived as to increase the outflow, but can only reduce the outflow to that which would have occurred under the natural outlet condition. Hence, lowering of the extreme high levels is possible, but support or raising of the low levels is not.

Table A-7 summarizes the effect of the various plans on the levels of the Great Lakes. The table also contains the basis-of-comparison levels employed in this study. Table A-38 presents a summary of whether or not these plans satisfy the International Joint Commission criteria for Lakes Superior and Ontario and the criteria established for evaluation herein for Lakes Michigan-Huron and Erie.

The hydrologic evaluation for Lake Superior on Table A-7 shows that the range of mean monthly lake levels on Lake Superior would be increased as a result of limited regulation of Lake Erie. This is due to the lowering of the minimum level. No impact is shown on the maximum level because the value shown occurs in the first year of the test period and the lake system had not yet adjusted to the new downstream conditions.

The hydrologic evaluation for Lakes Michigan-Huron on Table A-7 shows that the range of levels for all plans would be reduced in comparison to that which occurred under the basis-of-comparison. The table also shows that the impact on the maximum level is greater than that on the minimum level. This is due to the technique employed for regulation of Lake Erie and the effect of backwater from that lake to Lakes Michigan-Huron.

Table A-7 shows that under limited regulation of Lake Erie a lowering of the maximum level by up to 1.07 feet could occur. As a result of this lowering there would be an effect on all lakes of the system; raising Lake Ontario and lowering the upper Great Lakes. The table also shows that by employing only limited control of the outflow (no opportunity to reduce the flow below the natural outflow when water supply is low) there is a lowering effect on the minimum level.

The hydrologic evaluation for Lake Ontario shown on Table A-7 reflects the redistribution of the water supply from Lake Erie and the impact on Regulation Plan 1958-D. The table shows a small impact on the maximum level in comparison to that which occurs on the minimum level. This magnified effect is caused by the depletion of the Lake Erie water supply and the fixed minimum flow limitation of Plan 1958-D.

Table A-39 summarizes the impacts of one of the diversion management scenarios considered by the International Great Lakes Diversions and Consumptive Uses Study Board on selected regulation plans. In general, a further lowering of the system is experienced with application of the diversion management scenario on the selected evaluation plans. This lowering would provide for further benefits to the coastal zone interests, while increasing negative impacts on the power and navigation interests.

In summary, limited regulation of Lake Erie provides for a general lowering of the system with impacts being felt both on the maximum and minimum levels. To reduce the impact on the minimum level would require a raising of the level at which an increase in outflow from Lake Erie is implemented. This, in turn, would reduce the lowering of the maximum levels shown. Combining the work of the International Great Lakes Diversions and Consumptive Uses Study Board with limited regulation produces a further lowering with associate increases in benefits and losses.

Table A-33 shows that, with modification to the Lake Ontario regulation plan, impacts resulting from Lake Erie regulation can be offset and general improvement in the regime of levels effected. To provide these improvements requires excavation in the St. Lawrence River. This excavation would be of the same general magnitude as that required under the basis-of-comparison by regulation Plan 1958-D to satisfy the IJC criteria as written.

ANNEX A

CONVERSION FACTORS

(BRITISH TO METRIC UNITS)

1 cubic foot per second (cfs) = 0.028317 cubic metres per second (cms)

1 cfs-month = 0.028317 cms-month

1 foot = 0.30480 metres

1 inch = 2.54 centimetres

1 mile (statute) = 1.6093 kilometres

1 ton (short) = 907.18 kilograms

1 square mile = 2.5900 square kilometres

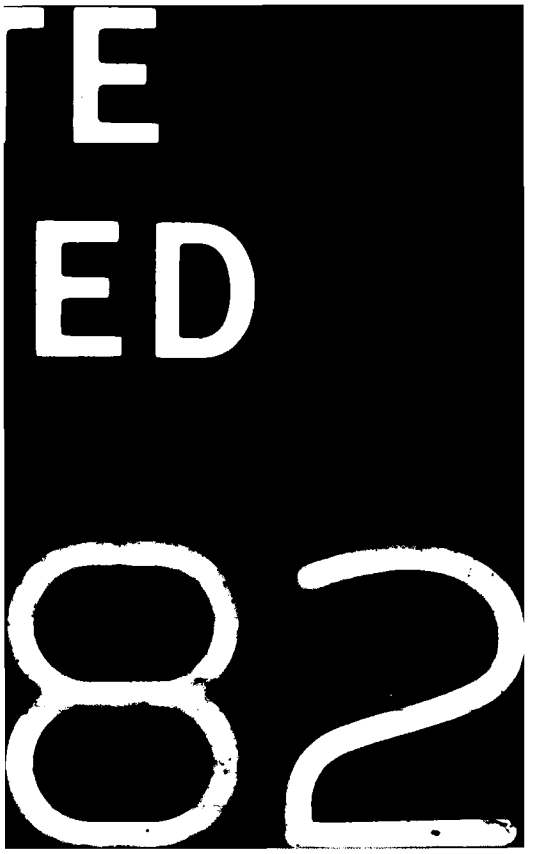
1 cubic mile = 4.1682 cubic kilometres

Temperature in Celsius: °C = (°F - 32) X 1.8

1 acre-feet = 1,233.5 cubic metres

1 gallon (U.S.) = 3.7853 litres

1 gallon (British) = 4.5459 litres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